AD-A016 246

SOVIET SEISMOGRAPHIC STATIONS AND SEISMIC INSTRUMENTS. PART II

C. Shishkevish

RAND Corporation

Prepared for:

Defense Advanced Research Projects Agency

June 1975

Second in a series on Soviet seismographic stations and seismic instruments, this report deals mainly with instruments and components developed since 1960, summarizing all the useful information published in Soviet scientific literature through June 1975. Among the conclusions: (1) Short-period seismometer design is constrained by massiveness. (2) Long-period seismometers are not so mechanically and geometrically precise as modern U.S. types. (3) Mechanical gain/attenuation is widely obtained by varying the coil position. (4) Response curves are more heavily damped. (5) Short-period galvanometers are well developed. (6) Older solid-state amplifiers are 1-2 orders of magnitude noisier than American ones. (7) FM tape recording is reasonably well developed. (8) Digital systems are few and rather primitive. (9) FM telemetry is little used. (10) Photo-optical technology is well developed. (11) Recording is narrow-band, emphasizing the response needed in analysis. Appendixes give the main parameters of the computers used and list new seismographic stations. Refs. (See also R-1204-ARPA, R-1652-ARPA.) (MW)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER R-1647-ARPA	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Soviet Seismographic Stations and Seismic Instruments, Part II		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) C. Shishkevish		8. CONTRACT OR GRANT NUMBER(s) DAHC15-73-C-0181
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Rand Corporation 1700 Main Street Santa Monica, Ca. 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency Department of Defense Arlington, Va. 22209		12. REPORT DATE June 1975
		13. NUMBER OF PAGES 168
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Seismographs
Soviet Union

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

see reverse side

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

304147

ARPA ORDER NO.: 189-1
6L10 Technology Assessments Office

ADA016246

R-1647-ARPA
June 1975

Soviet Seismographic Stations and Seismic Instruments, Part II

Charles Shishkevish

A Report prepared for

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

Rand
SANTA MONICA, CA. 90406

The research described in this Report was sponsored by the Defense Advanced Research Projects Agency under contract No. DAHC15-73-C-0181. Reports of The Rand Corporation do not necessarily reflect the opinions or policies of the sponsors of Rand research.

PREFACE

This is Part II of a two-part Report prepared under a continuing Rand study, sponsored by the Defense Advanced Research Projects Agency, of selected areas of Soviet science and technology. It presents data from open-source literature on Soviet seismographs -- most of them developed since 1960 -- and on their components and related equipment. Part I, R-1204-ARPA, published in May 1974, contains a general description of Soviet seismographic stations, with particular emphasis on seismograph systems, instrumental constants, and seismograph magnification curves.

The Report is intended primarily for U.S. seismologists working with Soviet seismic data and for those interested in recent Soviet instruments developed for seismological research and in their ability to record both natural and man-made seismic events. Soviet strong-motion and vibration-and-blast seismographs are dealt with in a separate Report by the same author, *Soviet Strong-Motion and Vibration-and-Blast Seismographs*, R-1652-ARPA, July 1975.

SUMMARY

This Report is the second of two parts dealing with Soviet seismographic stations and seismic instruments.* It deals mainly with seismic instruments and components developed since 1960 and thus excludes such older models as the SK broadband, general-purpose seismograph, the short-period SKh and SKM instruments, and the Galitzin seismographs, a few of which are still in operation.

This Report is divided into six chapters. Chapter I deals with short-period and intermediate-band seismographs and includes detailed descriptions of seismometers, galvanometers, amplifiers, recording systems, and the best known seismograph systems formed by combining these components. Chapter II examines long-period instruments, including the excellent long-period galvanometers developed in the Soviet Union, East German galvanometers, and long-period seismometers and seismographs. Chapter III is devoted to special seismograph station networks, the Soviet equivalent of seismic arrays. Considerable information is available on the KOD digital seismograph networks, which were developed exclusively for detection and identification of nuclear explosions, on the more recent Triangle network, and on the simple networks for earthquake prediction in Tashkent and Alma-Ata. Chapter IV summarizes the relatively scarce data on short-to-intermediate period and long-period, multiple band-pass, spectral analyzing seismographs consisting of a seismometer, a variable-gain, broadband amplifier, band-pass channel filters, and a light-beam oscillograph. Chapter V reviews Soviet strainmeters. Time-service equipment, magnetic drum recorders, and analog-to-digital converters are reviewed in Chapter VI.

The Report summarizes all of the useful information on seismic instruments published in Soviet scientific literature through June 1975.

---

*Part I, R-1204-ARPA, published in May 1974, summarizes the data on 168 seismographic stations known to be operating in the Soviet Union in 1970 and on their seismographs. A separate Report, *Soviet Strong-Motion and Vibration-and-Blast Seismographs*, R-1652-ARPA, was published in July 1975.

Preceding page blank

(Dozens of articles beyond those listed in the bibliography were used to evaluate certain contradictory data that appeared in descriptions of earlier models of instruments and components.) As a result of a time lag between the development of an instrument or a component and publication of its description this Report probably reflects the status of Soviet seismographic instruments at the end of 1972. Wherever possible, the technical specifications given refer to the latest model of the instrument.

The Report includes two appendixes. Appendix A gives the technical specifications of Soviet computers used in seismology. Appendix B summarizes information on Soviet seismographic stations that has become available since the publication of Part I of this Report.

The most important conclusions concerning Soviet seismographic instruments are as follows:

(1) Short-period seismometer design is constrained by a tendency toward massiveness, probably the result of low-output coil-magnet systems and noise levels in amplifiers and galvanometers. Magnification of 20,000 to 50,000 at 1 Hz is considered high gain. Even the borehole 1-Hz seismometer is a zero-length-spring pendulum design.

(2) Soviet seismologists show more interest in systems with flat response in the 1-to-10-sec period band than do U.S. seismologists. Except possibly for the most recently designed, experimental SVD-III and feedback-controlled models, Soviet long-period seismometers, with upper-period limits of near 25 sec and peak system magnifications of 1000, are apparently not as mechanically and geometrically precise as the modern U.S. Press-Ewing types.

(3) Wide use is made of mechanical gain (or attenuation). This is obtained by varying the coil position relative to the center of oscillation of the pendulum.

(4) In shaping response curves of Soviet instruments, much greater use is made of heavy damping than is made in the more conventional, critically damped models common in U.S. systems.

(5) Galvanometers are well developed for short-period applications and reflect the current state of the art at 100- to 500-sec periods.

(6) The noise of older Soviet solid-state amplifiers is one to two orders of magnitude higher than that of U.S. models.

(7) Frequency-modulated magnetic tape recording, while not standardized, seems to be well developed for slow-speed work, with reasonable signal-to-noise ratios.

(8) Digital systems are few, special purpose, and rather primitive.

(9) FM telemetry, both RF and audio frequency, is in use at a few networks, but not generally applied.

(10) Photo-optical technology is well developed as evidenced in the microphotorecorder.

(11) In recording, the emphasis seems to be on obtaining the records with the response needed in analysis -- as opposed to broadband, wide-dynamic-range recording and subsequent processing. This is also partially true in the few digital systems, where limited word lengths and sample rates necessitate some degree of signal conditioning. This is doubtless a consequence of the inaccessibility of computer-processing facilities for routine seismological studies.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Carl Kisslinger of the Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, and to T. V. McEvilly of the University of California, Berkeley, for their reviews of this Report and valuable comments and to Dr. McEvilly, especially, for discussions of various technical problems.

Preceding page blank

CONTENTS

I. SHORT-PERIOD AND INTERMEDIATE-BAND SEISMIC INSTRUMENTS

A. SEISMOMETERS

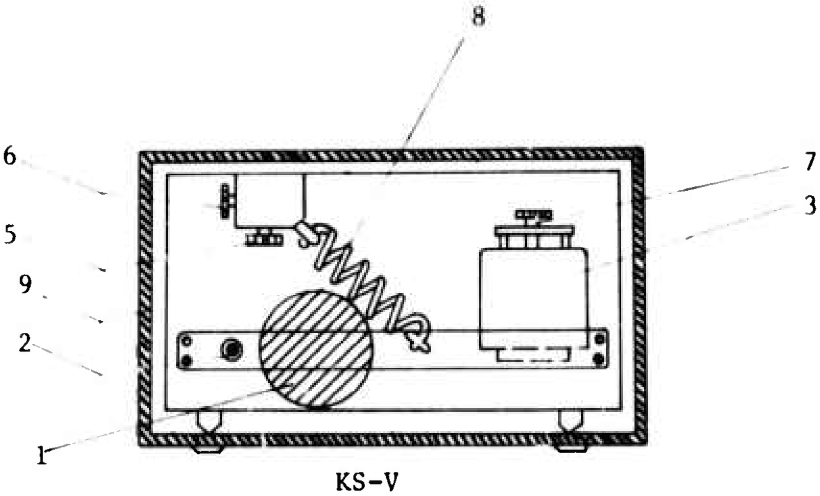
1. KS [1]

The recently developed short-period, high-gain KS seismometers (Fig. 1) are designed primarily for visual recording of the vertical and horizontal components of displacement. Both the horizontal (KS-G) and vertical (KS-V) seismometers are pendulum instruments equipped with a single moving-magnet, stationary-coil transducer with electromagnetic damping and a magnetic shunt which makes it possible to adjust its sensitivity 10 to 15 percent. The natural period of KS seismometers is adjustable between 0.8 and 4 seconds. The seismometers are intended for operation under stationary and field conditions at temperatures between -30°C and +40°C and a relative humidity of up to 95 percent. The technical specifications of KS are as follows:

Natural period	1.5 sec (nominal)
Reduced length	0.18 m
Moment of inertia	0.35 $kg \cdot m^2$
Signal-coil sensitivity*	300 V/(m/sec)
Damping-coil sensitivity*	280 V/(m/sec)
Calibration-coil sensitivity* ..	15 V/(m/sec)
Signal-coil resistance	1250 ohms
Damping-coil resistance	1100 ohms
Calibration-coil resistance	160 ohms
Dimensions	85.8 x 36.6 x 42.2 cm
Weight	84 kg

---

*The coil sensitivity (S_{coil}) is the coil output for motion, velocity in m/sec, of the center of oscillation of the pendulum, which is the steady point of the pendulum for high-frequency motion. Coil sensitivity can be converted to the generator constant by multiplying it by the reduced length and dividing by the distance between the hinge and the coil.



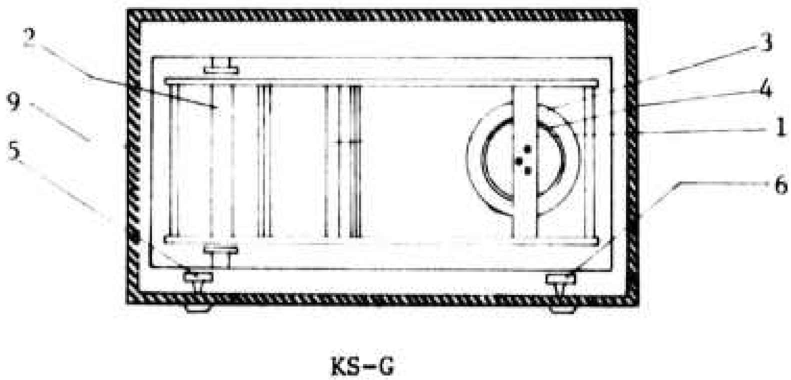
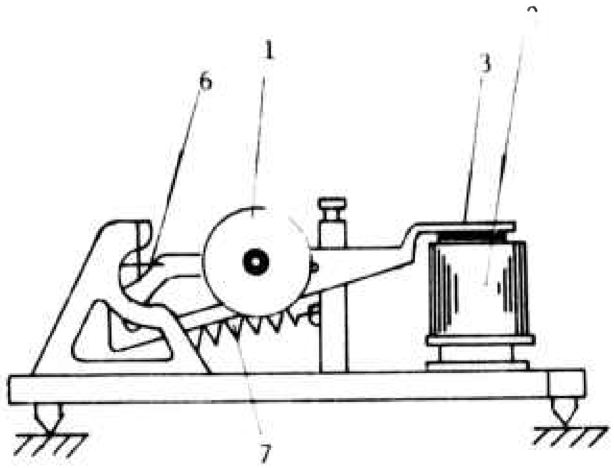


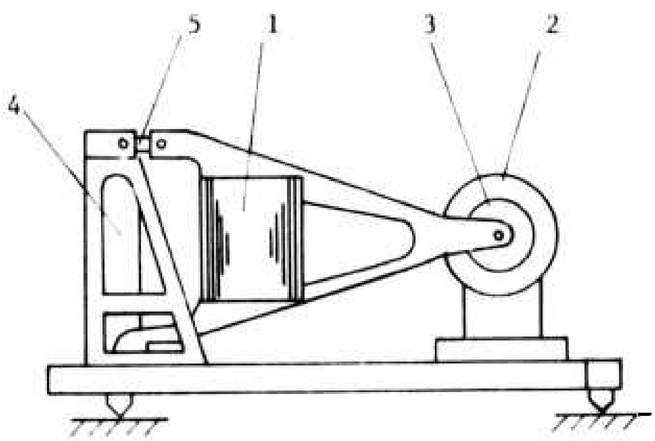
Fig. 1 -- Schematic drawings of the KS-V and KS-G seismometers [1]
1 - inertial mass
2 - axis of rotation of the pendulum
3 - moving magnet
4 - fixed coil
5 - pendulum-equilibrium-adjustment knob
6 - period adjustment knob
7 - magnetic shunt
8 - zero-length spring
9 - frame

2. SKM-3 [1,2]

The standard, widely used, short-period SKM-3 seismometers (Fig. 2) are designed primarily for galvanometric recording of the vertical and horizontal components of displacement with amplitudes between 0.01 μm and 1 mm in the period range 0.2 and 10 to 15 sec. Each horizontal (SGKM-3) and vertical (SVKM-3) seismometer is a high-gain, pendulum instrument equipped with an electromagnetically damped



SVKM-3



SGKM-3

Fig. 2 -- Schematic drawings of the SVKM-3 and SGKM-3 seismometers [1]
1 - pendulum
2 - permanent magnet
3 - signal coil
4 - suspension wire
5 - flat hinges
6 - two pairs of crossed flat hinges
7 - helical spring

moving-coil transducer. The natural period of SKM-3 seismometers is adjustable between 1 and 10 seconds. They are intended for operation under stationary and field conditions at temperatures between -30°C and +40°C and a relative humidity of up to 95 percent. The technical specifications of the SKM-3 are as follows:

Natural period	1.6 sec (nominal)
Reduced length	0.16 to 0.17 m
Moment of inertia	0.3 kg·m^2
Signal- and damping-coil sensitivities	60 to 70 V/(m/sec)
Signal- and damping-coil resistances	40 ohms
Dimensions	31 x 38 x 75 cm
Weight	50 kg

3. USF-3M [1,2]

The USF-3M is a short-period, high-gain pendulum seismometer with electromagnetic damping designed for galvanometric and visual recording of either vertical or horizontal components of displacement. It is equipped with a signal and a damping coil inserted into separate air gaps of a permanent magnet. Figure 3 shows the pendulum and the coil-magnet assembly of the USF-3M. High sensitivity of the transducer is achieved by allowing both the coils and the magnet to move in opposite directions and by connecting the coils to the pendulum by means of a lever. The natural period of the USF-3M seismometer is adjustable between 0.2 and 3 sec. The USF-3M is changed from a horizontal to a vertical seismometer and vice versa by rotating the seismometer assembly 90° around the horizontal axis and by adjusting the helical spring. It is intended for operation at temperatures between -40°C and +50°C and a relative humidity of up to 95 percent. The technical specifications of the USF-3M are as follows:

Natural period	1.5 sec (nominal)
Reduced length	0.24 m
Moment of inertia	0.2 kg·m^2
Signal-coil sensitivity	114 V/(m/sec)
Damping-coil sensitivity	38 V/(m/sec)
Signal-coil resistance	230 ohms
Damping-coil resistance	70 ohms
Dimensions	33 x 20 x 16 cm
Weight	12 kg

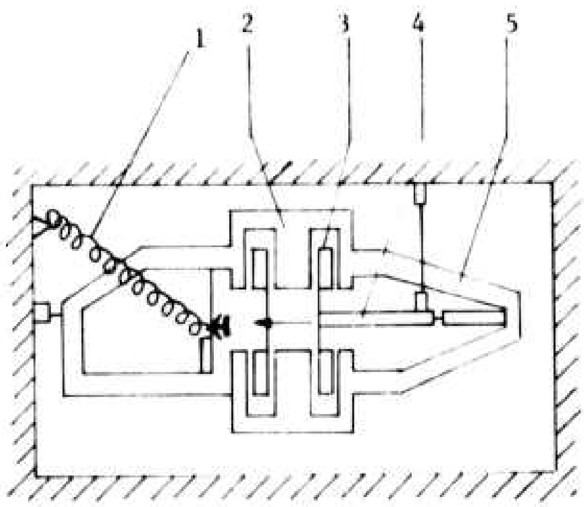


Fig. 3 -- Schematic drawing of the pendulum and the coil-magnet assembly of the USF-3M seismometer [2]
1 - helical spring
2 - permanent magnet
3 - coils
4 - additional lever
5 - pendulum

4. USF-4 [3]

The USF-4 short-period, high-sensitivity pendulum seismometer with a velocity transducer and electromagnetic damping is an improved model of the USF-3M. The USF-4, which can be used either as a horizontal or a vertical seismometer, is equipped with signal, damping, and calibration coils and two independent coil-magnet assemblies. High-sensitivity is achieved by making both the coils and the magnets free to move in opposite directions and by connecting the coils to the pendulum by means of a lever. The seismometer is equipped with an automatic zero-position pendulum-correction device and a remote period-adjustment control. Its natural period is adjustable between 0.5 and 5 sec. Each of the two coil-magnet assemblies can be used independently with short- and long-period galvanometers for photographic recording or with short- and long-period amplifiers for visual recording. The major specifications of the USF-4 are as follows:

Natural period	1.5 sec (nominal)
Reduced length	1.0 to 0.226 m
Moment of inertia	0.45 to 0.5 $kg \cdot m^2$
Signal- and damping-coil sensitivities	70 to 310 V/(m/sec)
Signal- and damping-coil resistances	5000 ohms
Calibration-coil resistance	50 ohms
Dimensions	56 x 25 x 33 cm
Weight	27 kg

5. VEGIK [4]

Developed in the early 1950s, the VEGIK seismometer (Fig. 4) was designed primarily for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between a fraction of a micrometer and 2 mm in the period range 0.01 to 1 sec. It is an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping. Although intended originally as a blast seismometer, it has found wide application in seismology. A system consisting of VEGIK seismometers and a photographic recorder can be used to register velocities rather than displacements by simply replacing the overdamped galvanometers with a natural frequency $f_s \leq 15$ Hz with high-frequency galvanometers. The natural period of the VEGIK is adjustable between 0.8 and 1.5 sec. A helical spring in the vertical seismometer is used to compensate the force of gravity and to adjust its period. A pendulum-positioning knob and a period-control knob are used when the VEGIK is responding to horizontal motion. The seismometer is intended for operation under stationary or field conditions, at temperatures between -20°C and +40°C, and a relative humidity of up to 90 percent. The technical specifications of the VEGIK seismometer are as follows:

Natural period	1 sec (nominal)
Reduced length	0.097 m
Signal- and damping-coil sensitivities	20 V/(m/sec)
Signal- and damping-coil resistances	45 ohms
Moment of inertia	0.1 kg·m^2
Dimensions	11 x 16 x 34 cm
Weight	10 kg

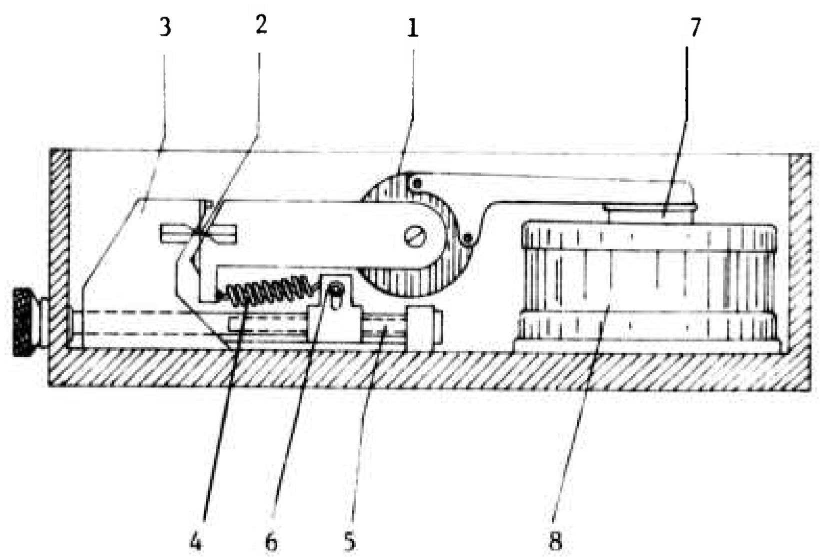


Fig. 4 -- Schematic drawing of the VEGIK seismometer [4]
1 - pendulum
2 - axis of rotation formed by two pairs of crossed steel hinges
3 - mast
4 - helical spring
5 - pendulum-positioning screw
6 - period-control screw
7 - coil
8 - permanent magnet

6. SM-2M [1,5]

The SM-2M (Fig. 5), an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping is an improved version of the VEGIK seismometer. It is intended primarily for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between 0.1 μm and 3 mm in the frequency range 0.7 to 200 Hz.

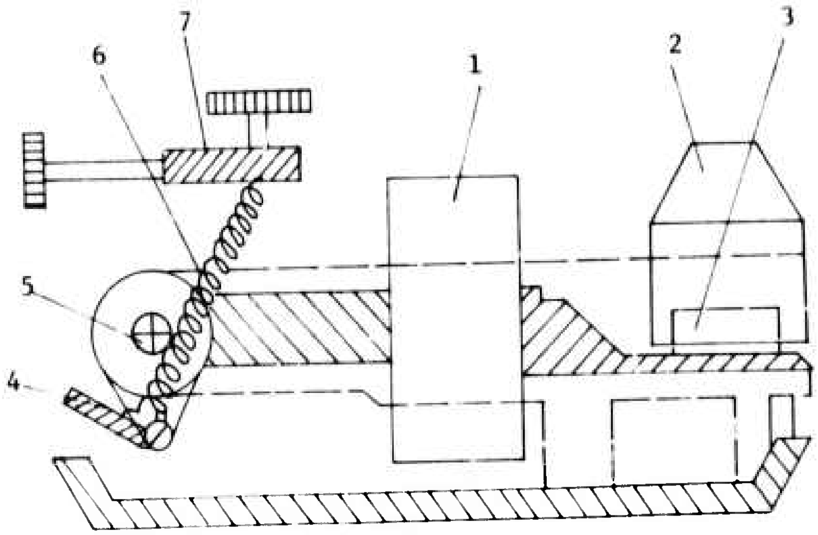


Fig. 5 -- Schematic drawing of the SM-2M seismometer [1]
1 - pendulum
2 - permanent magnet
3 - signal coil
4 - temperature-compensation device
5 - replaceable crossed flat hinges forming the axis of rotation
6 - helical spring
7 - spring- and period-adjustment mechanism

The SM-2M is equipped with a helical spring which compensates the force of gravity in the vertical seismometer and provides an adjustable astatizing force in the horizontal seismometer. A system consisting of SM-2M seismometers and a light-beam oscillograph can also be used to record velocities rather than displacements by replacing the overdamped galvanometers ($f_s \leq 15$ Hz) with high-frequency galvanometers.

The SM-2M can be changed from a horizontal to a vertical seismometer and vice versa by rotating the seismometer assembly 90° around the horizontal axis and adjusting the helical spring. The SM-2M can be rigidly attached to an object and operated at any angle between 0 and 180° to the horizontal. It is equipped with a temperature-compensation device which maintains the equilibrium position of the pendulum when temperature varies ±20°C from the nominal value. The natural period of the SM-2M is adjustable between 0.7 and 2 sec. It is hermetically sealed and is watertight up to 1.5 m of water. The technical specifications of the SM-2M are as follows:

Natural period	1.5 sec (nominal)
Damping factor	0.6
Reduced length	0.087 m
Signal-coil sensitivity	37 V/(m/sec)
Damping-coil sensitivity	12 V/(m/sec)
Signal-coil resistance	130 ohms
Damping-coil resistance	45 ohms
Moment of inertia	0.0085 $kg \cdot m^2$
Dimensions	14.5 x 16.7 x 23 cm
Weight	5.6 kg

When first developed, the SM-2M had a single coil. This was a low-impedance coil when the SM-2M was coupled with overdamped galvanometers with $f_s \leq 15$ Hz for use primarily in engineering work and a high-impedance coil when the seismometer was coupled to an amplifier. Damping could be introduced by shunting the coil by means of an external switch. The technical specifications of the older SM-2M seismometer, with a high-impedance coil, which differ from the one described above are:

Coil resistance .... 3000 ohms

Shunt resistance .... 6000 ohms

Equivalent resistance .... 2000 ohms

Signal-coil sensitivity with the shunt connected .... 165 V/(m/sec)

Electromagnetic damping factor.. 0.5

7. SM-3 [1]

The SM-3 (Fig. 6), an electromagnetic, moving-coil, pendulum seismometer with electromagnetic damping is an improved version of the SM-2M. Structural changes slightly improved its response to large amplitude displacements (from 3 mm for SM-2M to 5 mm for SM-3) and extended the lower limit of its frequency range (from 0.7 Hz for SM-2M to 0.5 Hz for SM-3). However, the major improvement of the SM-3 over the SM-2M is the convenience and ease of its operation. The natural period of the SM-2M is adjustable between 0.7 and 3 sec. The technical specifications of the SM-3 are as follows:

Natural period .... 2 sec (nominal)

Damping factor 0.6

Reduced length .... 0.085 m

Signal- and damping-coil sensitivities .... 20 V/(m/sec)

Signal- and damping-coil resistances .... 65 ohms

Moment of inertia .... 0.0089 kg·m^2

Weight .... 5.5 kg

In all other respects the SM-3 seismometer appears to be identical to the SM-2M.

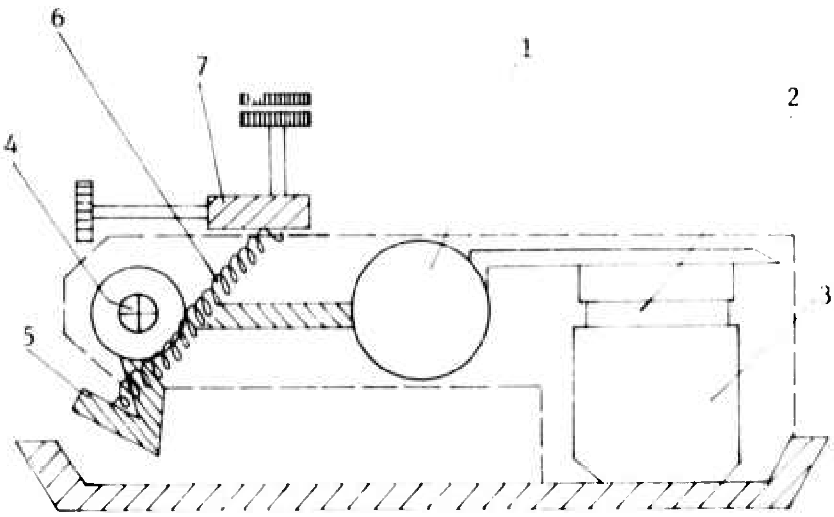


Fig. 6 -- Schematic drawing of the SM-3 [1]
1 - pendulum
2 - coil
3 - permanent magnet
4 - crossed flat hinges forming the axis of rotation
5 - temperature-compensation device
6 - helical spring
7 - spring- and period-adjustment mechanism

8. S5S [6,7]

The S5S (Fig. 7) is an electromagnetic, moving-magnet, double-pendulum seismometer with adjustable electromagnetic damping intended primarily for galvanometric recording of either vertical or horizontal components of displacement with amplitudes between 0.01 μm and 15 mm in the period range 0.01 to 5 sec. A system consisting of S5S seismometers and oscillographs can also record velocities rather than displacements by replacing the overdamped galvanometers with $f_s \leq 15$ Hz with high-frequency galvanometers. The S5S can be changed from a horizontal to a vertical seismometer by rotating the seismometer assembly 90° around the horizontal axis and adjusting the spring. The pendulum of the seismometer consists of two rigidly connected cylindrical

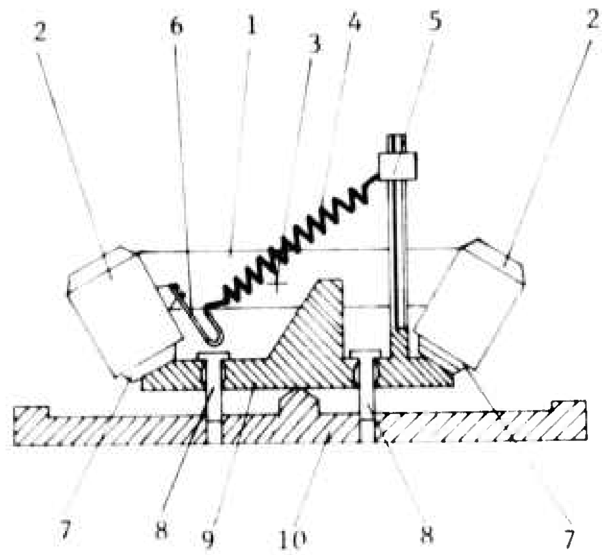


Fig. 7 -- Schematic drawing of the S5S seismometer [1]
1 - pendulum
2 - magnet
3 - axis of rotation of the pendulum
4 - zero-length spring
5 - equilibrium position control
6 - temperature-compensation device
7 - signal and damping coils
8 - period-adjustment screw
9 - base of stand
10 - base of frame

magnets located on opposite sides of the axis of rotation. The pendulum is suspended from the stand by two pairs of crossed, flat hinges forming the axis of rotation. A helical spring between the mast and the temperature-compensation device, located on the side of one of the magnets, balances the weight of the pendulum. The seismometer is equipped with two stationary coils (signal and damping) attached to the stand. Its natural period can be adjusted between 1 and 5 sec by changing the angle between the stand and the base of the frame. It is hermetically sealed and can operate at temperatures between -50°C and +50°C. The technical specifications of the S5S are as follows:

Natural period	5 sec (nominal)
Reduced length	0.425 m
Signal-coil sensitivity	12.8 V/(m/sec)
Damping-coil sensitivity	6.3 V/(m/sec)
Signal- and damping-coil resistances	88 ohms
Moment of inertia	0.066 kg·m^2
Dimensions	15 x 16 x 36 cm
Weight	11 kg

B. GALVANOMETERS

1. GK-VIIM [1,2]

The GK-VIIM galvanometers (Fig. 8) are used with SK and SKD as well as most moderate-to-high-gain, short-period, photographically recording seismographs. Each galvanometer is inserted into a separate magnet assembly equipped with a magnetic shunt. The galvanometer coil consists of 160 turns of 0.08-mm-diameter copper wire. The suspension is made of two phosphor bronze ribbons, 7 to 8 μm thick and 0.15 to 0.18 mm wide, which also are the current leads. The maximum magnetic field strength in the air gap is 2000 G. The technical specifications of the GK-VIIM are given in Table 1, where T_g is the galvanometer period, C_i is the current sensitivity, R_g is the coil resistance, CDRX is the external resistance at critical damping, and K_g is the moment of inertia. These galvanometers are intended for operation under stationary or field conditions at temperatures between -30°C and +40°C and a relative humidity not exceeding 95 percent. The dimensions of the GK-VIIM are 15 x 15 x 30 cm and they weigh 6.4 kg.

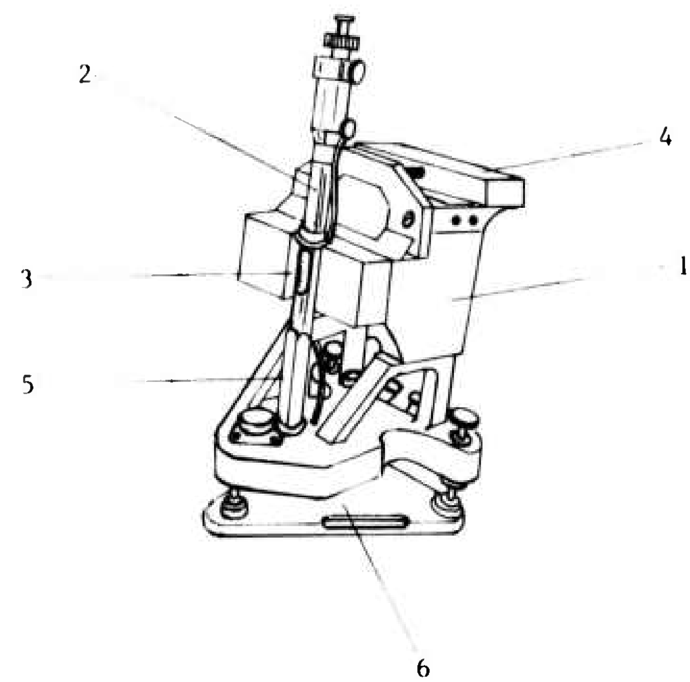


Fig. 8 -- Schematic drawing of the GK-VIIM galvanometer [1]
1 - permanent magnet
2 - pencil galvanometer insert
3 - window
4 - magnetic shunt
5 - period-adjustment scale
6 - base plate

Table 1 [1]

TECHNICAL SPECIFICATIONS OF THE GK-VIIM GALVANOMETER

T_g (sec)	C_i (A/mm at 1m)	R_g (ohms)	CDRX (ohms)	K_g ($kg \cdot m^2$)
1.1 to 1.3	1×10^{-8}	49 ± 3	850	$(4 \text{ to } 5) \times 10^{-9}$
0.55 to 0.65	8×10^{-9}	75 ± 7	320	$(1.6 \text{ to } 2.4) \times 10^{-10}$
0.3 to 0.4	1.7×10^{-8}	70 ± 7	200	$(1.6 \text{ to } 2.4) \times 10^{-11}$
0.18 to 0.20	7×10^{-8}	65 ± 7	65	$(1.6 \text{ to } 2.4) \times 10^{-11}$

The photorecording equipment used at Soviet permanent seismographic stations consists of sets of three GK-VIIM galvanometers, three collimators, and a PS-2M drum recorder, installed in a special dark room.

2. GB-III and GB-IV [1,2,8,9]

The GB-III and GB-IV are the two basic galvanometer types used widely in seismology and seismic engineering as the sensing elements of light-beam oscillographs. Each type includes several series that differ in their natural frequency, current sensitivity, coil resistance, and other parameters. Soviet seismologists separate all galvanometers used in seismic applications into two groups: (a) high-frequency galvanometers with the natural frequency $f_g \gtrsim 30$ Hz and optimal damping of about 0.7 and (b) heavily overdamped with $f_g \lesssim 15$ Hz, optimal damping as high as 25 to 30 times critical damping, and high coil resistance. The response of high-frequency galvanometers extends between approximately one-half of its natural frequency and dc; that of a heavily damped galvanometer is symmetric about its natural frequency.

The GB-III and GB-IV galvanometers are intended for use primarily with galvanometrically recording strong-motion instruments. The GB-III and GB-IV are interchangeable, with two GB-IV galvanometers used for each GB-III. The smaller size of the GB-IV is achieved by using a narrower, lighter coil than in the GB-III.

A schematic drawing of the GB-III and GB-IV galvanometers is shown in Fig. 9. Table 2 gives the technical specifications of galvanometers recommended for use in seismic engineering and seismology. (In this table f_g is the natural frequency of the galvanometers, R is the external resistance at 0.7 critical damping, I_{max} is the maximum current, and the other symbols are the same as those used in Table 1.)

According to [10], the main reason that both the GB-III and GB-IV series galvanometers are being manufactured is the inability of Soviet industry to fabricate narrow suspensions with a torsion constant sufficiently low for low-frequency ($f_g < 5$ Hz) GB-IV galvanometers. Whenever both GB-III and GB-IV galvanometers with the same natural frequency are available, it is usually preferable to use GB-IV models.

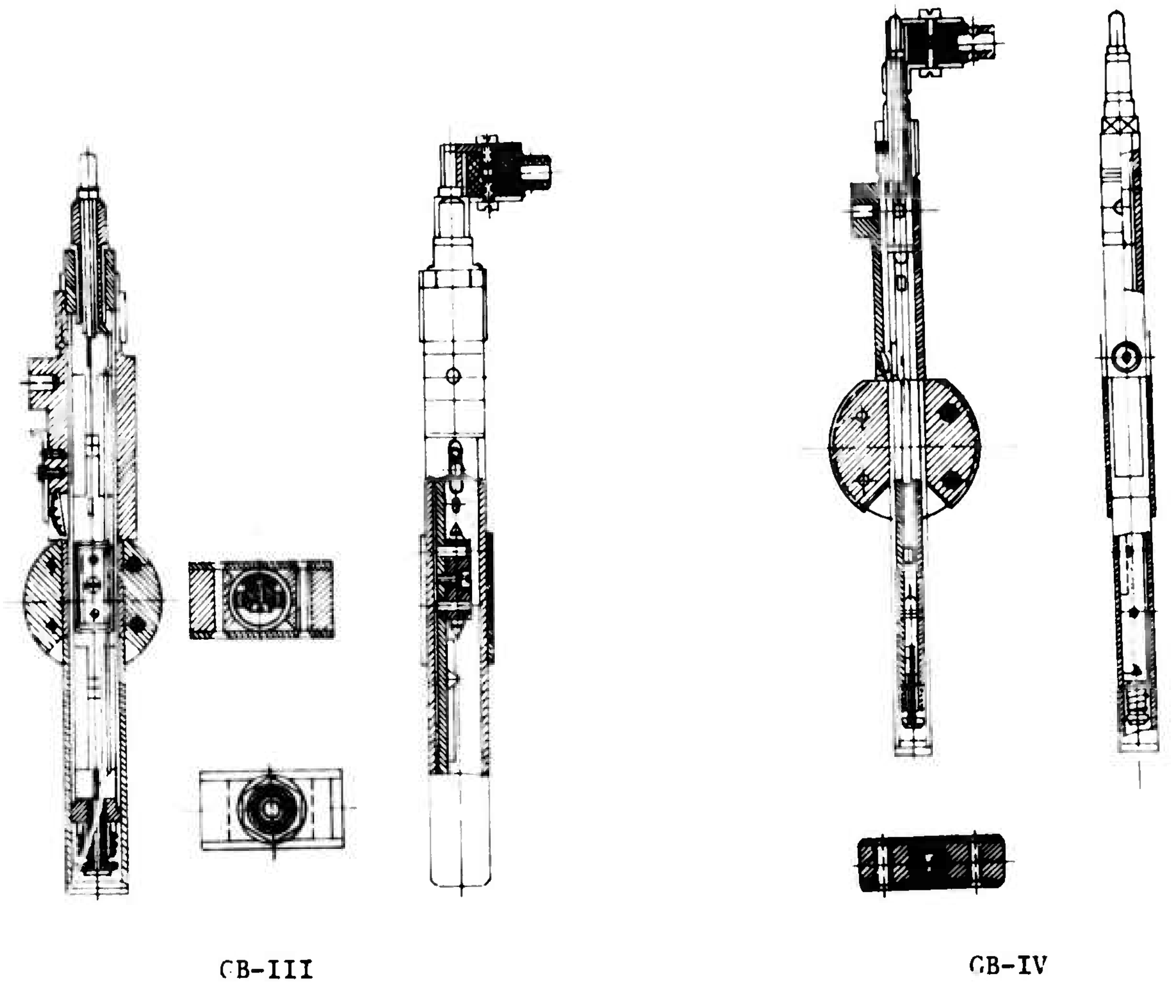


Fig. 9 -- Schematic drawings of the GB-III and GB-IV galvanometers [6]

Table 2 [1,11]

TECHNICAL SPECIFICATIONS OF GB-III AND GB-IV GALVANOMETERS

Galvanometer	f_g (Hz)	C_i (A/m at 1m)	R (ohms)	R (ohms)	I_{max} (mA)	K_g (kg·m^2)
GB-III-B-0.8	0.8	$2.5x10^{-9}$	52	5000		$1.20x10^{-9}$
GB-III-B-1	1.25	$4.0x10^{-9}$	64	6000	0.003	$1.15x10^{-9}$
GB-III-B-2.5	2.5	$1.5x10^{-8}$	60	3000	0.011	$1.15x10^{-9}$
GB-III-B-5	5	$6.0x10^{-8}$	56	1500	0.044	$1.50x10^{-9}$
GB-III-B-10	10	$2.5x10^{-7}$	56	750	0.18	$1.15x10^{-9}$
GB-III-C-1	1.25	$1.6x10^{-9}$	400	42000	0.001	--
GB-III-C-2.5	2.5	$8.0x10^{-9}$	400	19000	0.006	--
GB-III-C-5	5	$30.0x10^{-8}$	400	9500	0.0022	--
GB-III-C-10	10	$1.2x10^{-7}$	400	4700	0.09	--
GB-III-BS-0.8	0.8	$5.0x10^{-9}$	52	800	0.004	$1.2x10^{-9}$
GB-III-BS-1.0	1.25	$1.0x10^{-8}$	64	950	0.008	$1.15x10^{-9}$
GB-III-BS-2.5	2.5	$4.0x10^{-8}$	60	420	0.03	$1.15x10^{-9}$
GB-III-BS-2.5	2.5	$1.4x10^{-8}$	76	360	0.01	$0.2x10^{-9}$
GB-III-BS-5	5	$1.5x10^{-7}$	56	220	0.1	$1.15x10^{-9}$
GB-III-BS-10	10	$5.0x10^{-7}$	56	110	0.4	$1.15x10^{-9}$
GB-III-3	5	$2x10^{-8}$	140	4000	--	$1.15x10^{-9}$
GB-III-BM-1	1.25	$2x10^{-9}$	76	4600	--	$0.2x10^{-9}$
GB-III-BM-2.5	2.5	$7x10^{-9}$	76	2300	--	$0.2x10^{-9}$
GB-III-BM-5	5.0	$3x10^{-8}$	76	1150	--	$0.2x10^{-9}$
GB-III-BM-10	10.0	$1.2x10^{-7}$	76	550	--	$1.15x10^{-9}$
GB-IV-B-1	20-30	$1.3x10^{-8}$	170.0	3200	--	--
GB-IV-B-2	60	$1.0x10^{-7}$	170.0	1050	0.04	--
GB-IV-B-3	120	$4.0x10^{-7}$	170.0	470	0.2	--
GB-IV-C-1	30	$2.0x10^{-8}$	58.0	1200	0.01	$4.5x10^{-12}$
GB-IV-C-2	60	$1.0x10^{-7}$	58.0	350	0.04	$4.5x10^{-12}$
GB-IV-C-3	120	$3.0x10^{-7}$	52.0	175	0.2	$4.5x10^{-12}$
GB-IV-S-5	5	$5.0x10^{-9}$	78	2600	0.002	$1.7x10^{-11}$
GB-IV-S-10	10	$2.0x10^{-8}$	54	1200	0.007	$9.4x10^{-12}$
GB-IV-S-15	15	$5.0x10^{-8}$	54	800	0.025	$9.4x10^{-12}$
GB-IV-SI-5	5	$8x10^{-9}$	65	5000	--	$1.5x10^{-10}$
GB-IV-SI-10	10	$3x10^{-8}$	65	2500	--	$1.5x10^{-10}$
GB-IV(M-001)	120	$4x10^{-7}$	54	liq.damp.	--	$4.5x10^{-12}$

This fact is easily verified by Table 2 which shows that the GB-IV galvanometers are more sensitive and have a lower moment of inertia than the GB-III galvanometers with the same natural frequency.

C. AMPLIFIERS

1. UPN-3 Amplifier System [12]

The UPN-3 is a transistorized, three-channel amplifier system intended for use with short-period electromagnetic seismometers and pen recorders. Each channel of the UPN-3 consists of three dc amplifiers. Negative current feedback is used for gain stabilization and for reducing the unbalance. Each channel is equipped with an LC and a low-pass integrating filter. The frequency response of the UPN-3 amplifier is shown in Fig. 10. The amplifier can be operated in the temperature range +5°C to +35°C with the gain not varying by more than ±5 percent from the nominal gain at +20°C. Its technical specifications are as follows:

Voltage gain	$\leq$70,000
Noise at the input	$\leq$1 μV rms
Input impedance	1300 ohms
Output impedance	two 160-ohm coils of GPT-II galvanometers used in hot-pen recorders
Output voltage	10 V
Power supply	127 or 220 V ac, 10 W
Dimensions	49 x 19.5 x 36.5 cm
Weight	12 kg

2. IPR Galvanometer Amplifier with a Parametric Variable-Reluctance Transducer [1,13]

The one-channel IPR amplifier system (Fig. 11) is intended for use with an electromagnetic seismometer and a pen recorder. Two thin copper plates are attached to the ends of the stop on top of the coil

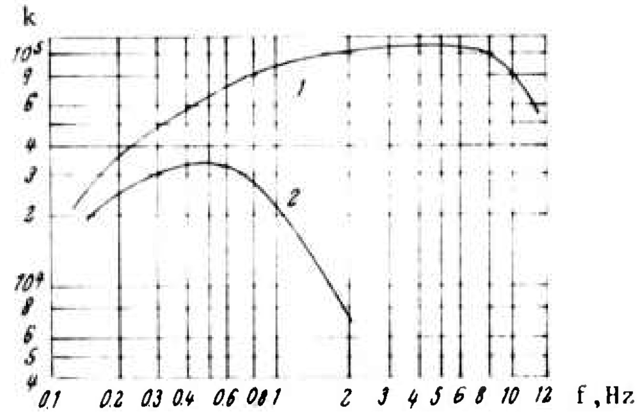


Fig. 10 -- Frequency response of the UPN-3 amplifier system [12]
1 - without the low-pass integrating filter
2 - with the low-pass integrating filter

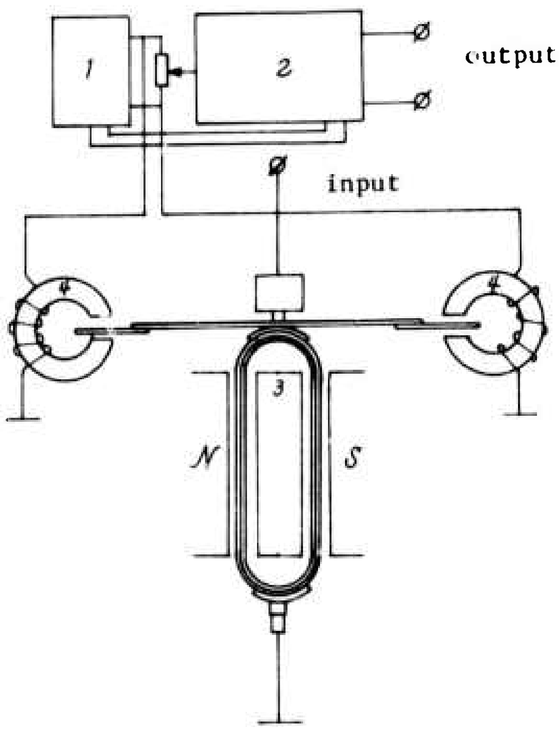


Fig. 11 -- Schematic drawing of the IPR galvanometer amplifier with a parametric variable-reluctance transducer [1]
1 - 2-kH sine-wave generator
2 - transistorized carrier-frequency amplifier
3 - galvanometer of the F117 phototube amplifier
4 - variable-reluctance transducer

of the galvanometer usually used in an F117 galvanometer phototube amplifier. The free ends are centered in the air gaps of two electromagnets, each consisting of a ferromagnetic split ring and a winding forming a bridge circuit connected to a source of 2-kHz sine-wave voltage. The voltage across the bridge diagonal is fed into a transistorized amplifier and then to a phase-amplitude modulation detector. Deflection of the galvanometer's coil and the stop unbalances the circuit, causing voltage to appear at the output of the amplifier. The IPR can be operated at temperatures between +10°C and +40°C and relative humidity of up to 80 percent. The technical specifications of the IPR amplifier are as follows:

Voltage gain	$\leq 10^6$
Input resistance (galvanometer-coil resistance)	56 ohms
Noise at the input	≤ 0.05 μV
Output voltage	±10 V
Output impedance	~50 ohms
Dynamic range	54 to 60 dB
Galvanometer period	2 to 4 sec
External critical-damping resistance	~1000 ohms
Power supply	127 or 220 V ac, 3 to 5 W
Dimensions	18 x 33 x 20 cm
Weight	1.5 kg

D. RECORDING SYSTEMS

1. Standard PS-3M Drum Recorder and Light-Beam Oscillographs

a. PS-3M [2,1]. The PS-3M is the standard drum recorder used with galvanometrically recording seismographs at Soviet seismographic stations. A 29-cm-wide, 90-cm-long loop of photographic paper is mounted on a drum rotating at a uniform speed and translated at a constant rate along a threaded shaft. In the older PS-2 models the drum was rotated by means of a weight-controlled mechanism regulated by a conical pendulum device. Time marks from an MKh marine chronometer were printed every minute. The newer PS-3M model is equipped with a more precise quartz timing system and a DSD-60 synchronous motor, with deviation from the constant rotation rate of 1 rev/min occurring only as a result of voltage fluctuations of the power supply. Precise time signals received by radio are recorded at unspecified time intervals. The PS-3M may be used at temperatures and relative humidity limited only by the photographic paper used with the recorder. The principal technical specifications of the PS-3M are as follows:

Rotation speeds	7.5, 15, 30, 60, 120, 240 mm/min
Translation rates	0.5, 0.7, 1, 1.25, 1.5, 2.5, 3.5, 5 mm/rev
Paper width	up to 28 cm
Paper length	90 cm
Power supply (motor only)	24 V, 4 W
Dimensions	60 x 35 x 45 cm
Weight	56 kg

b. OSB-VI-M [14]. The OSB-VI-M is a six-channel, light-beam oscillograph designed primarily for the registration of earthquakes. It records on a 28-cm-wide, 90-cm-long loop of photographic paper mounted on a drum rotated at a uniform speed by a synchronous motor. Translation rates between 0.5 and 3 mm/rev are achieved by means of a slowly turning mirror. The oscillograph is equipped with six GB-III or twelve GB-IV galvanometers. Time marks are printed on the paper in the form of breaks in the lines when a relay briefly disconnects the circuit between the power supply and the galvanometer illuminator. The OSB-VI-M is equipped with an automatic spot-brightness control described in [15]. In the absence of ac electricity, the drum can be driven by an external spring drive. It is intended for field and stationary use at temperatures between -10°C and +40°C and at relative humidity of up to 80 percent. The technical specifications of the OSB-VI-M light-beam oscillograph are as follows:

Optical lever	50 cm
Rotation rates with motor	15, 30, 60, 120, 240, 480 mm/min
with spring drive	30, 60, 120 mm/min
Rotation rate error	≤1%
Translation rates	0.5, 1, 2 mm/rev
Record duration with motor	12 hrs at 120 mm/min
with spring drive	8 hrs
Power supply	220 V ac, 20 W
Dimensions	67 x 43.5 x 35.5 cm
Weight	45 kg

c. OSB-IMp [16]. The OSB-IMp is a portable, light-beam oscillograph designed for continuous three-to-six channel recording on standard 12-cm-wide photographic paper that is either mounted on an enclosed drum or advanced at a uniform speed between cassette reels. It is equipped with a synchronous motor which has to be used with the cassette. The drum, however, can be driven by either the motor or an external spring drive, with a centripetal device for velocity control. The OSB-IMp is usually used with six GB-IV or, less frequently, with three GB-III galvanometers. The time marks from an outside clock are printed on the paper in the form of breaks in the lines when a relay briefly disconnects the circuit between the lamp illuminating the galvanometer mirror and the power supply. The oscillograph is equipped with a variable-width diaphragm rather than with an automatic spot-brightness control. Figure 12 shows a cross section of the OSB-IMp and Fig. 13, a schematic drawing of its optical system. The OSB-IMp is intended for operation at temperatures between -10°C and 30°C and relative humidity of up to 80 percent. The technical specifications of the OSB-IMp are as follows:

Number of channels	3 to 6
Mode of operation	Continuous
Optical lever	30 cm
Recording medium	Photographic paper 12 cm wide and 45 cm long for a drum and 10 m long for a film cassette

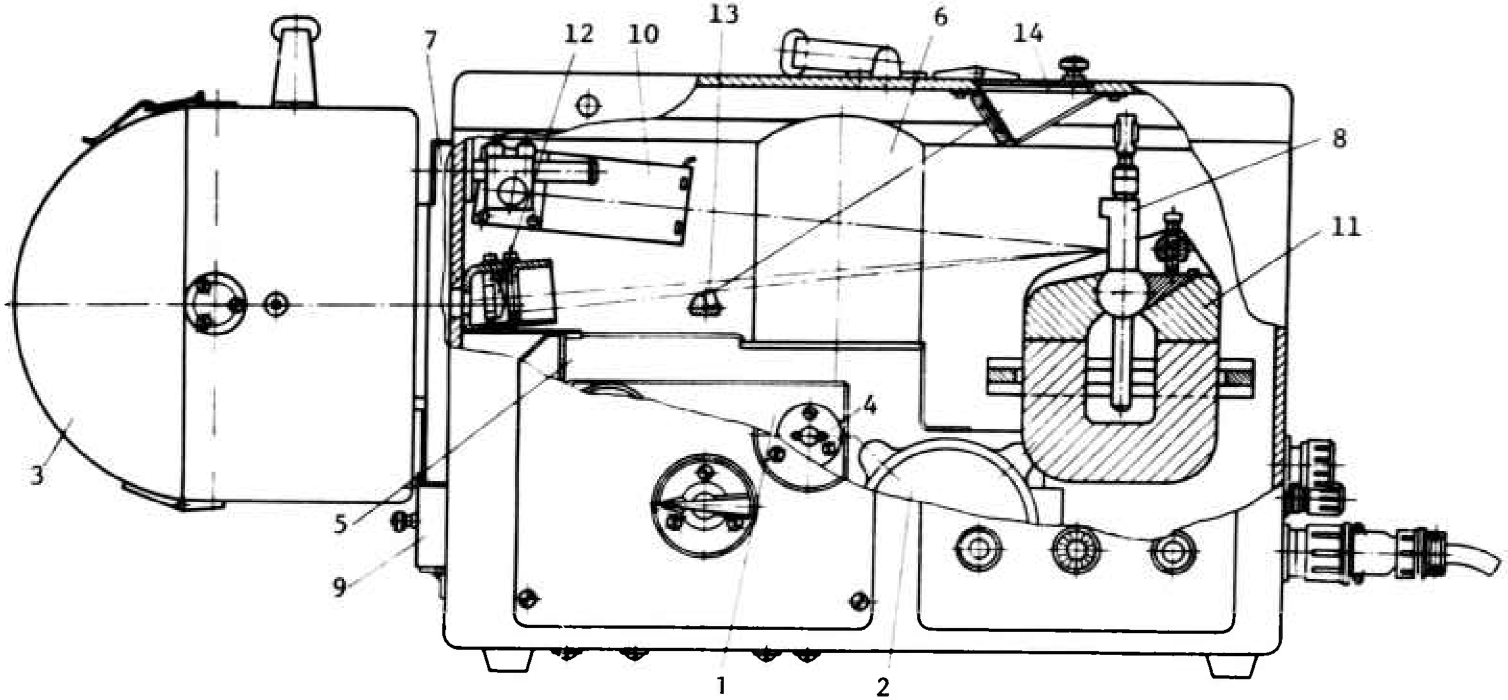


Fig. 12 -- Cross-sectional view of the OSB-IMp light-beam oscillograph [16]

1 - spring drive	8 - galvanometer
2 - synchronous motor	9 - interchangeable transverse motion gears
3 - drum	10 - light source
4 - winding mechanism	11 - galvanometer bank
5 - gear box	12 - cylindrical lens
6 - centripetal device for velocity control	13 - mirror
7 - transverse motion carriage	14 - trace-viewing window

Recording speed
  drum with motor .... 0.25, 0.5, 1, 2, 4, 8, 16, 32, 64 mm/sec

  drum with spring drive .... 0.125, 0.25, 0.5, 1, 2 mm/sec

  cassette with motor .... 0.156, 0.312, 0.625, 1.25, 2.5, 5, 10, 20, 40 mm/sec

Translation rates
  drum .... 0.5, 1, 2 mm/rev
  cassette 0

Record duration
  drum with motor .... 8 hrs at 1 mm/sec and 0.5 mm/rev

  drum with spring drive .... 8 hrs

Power supply .... 220 V ac, 30 W
  with spring drive .... 3 V dc, 0.5 W

Dimensions .... 59 x 30 x 28 cm

Weight .... 20 kg

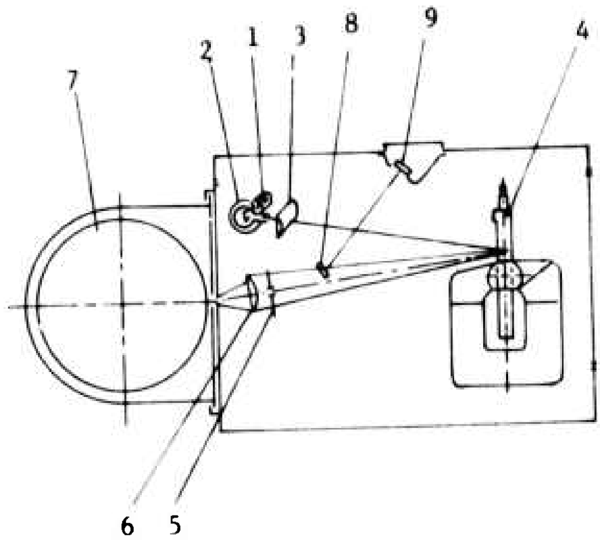


Fig. 13 -- Schematic drawing of the optical system of the OSB-IMp [16]
1 - lamp
2 - shielding cap
3 - cylindrical lens (probably oriented vertically)
4 - galvanometer with spherical lens and mirror
5 - variable-width diaphragm
6 - cylindrical lens
7 - drum
8 - mirror
9 - viewing window screen

2. PVZ-T* and PVZ-2 Ink-Pen Recorders [17]

The PVZ-T ink-pen recording system (Fig. 14) and the later model PVZ-2 are designed for high-gain registration of seismic events. The PVZ-T is a four-channel recorder, writing on a 29-cm-wide, 180-cm-long loop of paper mounted on a drum and a tension roller, rotated at a uniform speed by a specially designed low-power dc motor operated by a battery switched on by three photodiodes. The speed of the motor is controlled by a centripetal device consisting of three shutters with springs. The PVZ-T is equipped with a transistorized, low-noise amplifier system, consisting of a three-stage preamplifier with a gain of 200 and a separate power supply, both of which are usually placed with the seismometers and a three-stage, negative-feedback power amplifier with a maximum gain of 10^4. The sensitivity of the pen head is ~160 μA/mm at 1 m and the signal-coil impedance matched to that of the postamplifier, is 800 ohms. The damping factor of the pen at normal gain is usually adjusted to 0.4 to 0.5. The technical specifications of the PVZ-T ink-pen recorder are as follows:

Number of channels	1 to 4
Rotation rates	15, 30, 60, 120, 240 mm/min
Rotation rate error	0.5%
Translation rates	1.5 to 5 mm/rev
Record duration (three channels)	36, 24, 12, 8, 3 hrs
Maximum resonant frequency of pen	6 to 7 Hz
Pen sensitivity	160 μA/mm at 1 m ±20%
Maximum double amplitude	4 cm
Power supply	12 V dc, 2.5 W
Dimensions	94 x 70 x 44.5 cm
Weight	70 kg

*A portable, one-channel model of the PVZ-T is known as the KSE-1.

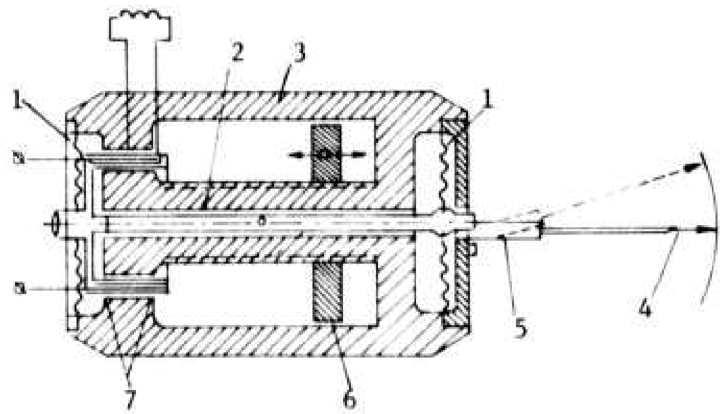


Fig. 14 -- Schematic drawing of the ink pen used in the PVZ-T recorder [17]
1 - springs
2 - rod
3 - magnetic circuit
4 - pen
5 - spring
6 - magnetic shunt
7 - signal and damping coils wound on a coil former rigidly attached to rod

3. Heated-Stylus Recorders

a. N-002 [18,19]. The N-002 (Fig. 15) is a three-channel hot-pen recorder that writes on a 30.5-cm-wide, 90-cm-long loop of heat sensitive paper mounted on a drum driven by a G-31 synchronous electric motor. The recorder is equipped with three GPT-II galvanometer pens (Fig. 16). Constant trace width is maintained independently of the deflection rate of the galvanometer pen, and thus independently of the amplitude and frequency of the input signal, by means of a power amplifier, which automatically adjusts the pen-heating current proportionally to the voltage fed to the pen. Time marks are printed on the heat-sensitive paper by means of a relay that briefly disconnects the circuit between the pen and the power supply and by means of a separate GPT-II pen. The recorder is intended for operation under stationary conditions at temperatures between 10°C and 40°C and a relative humidity of up to 80 percent. The N-002 is usually used with UPN-3M or IPR-M amplifiers, which are the latest models of the UPN-3 and IPR amplifiers described in Section I-C. The technical specifications of the N-002 hot-pen recorder are as follows:

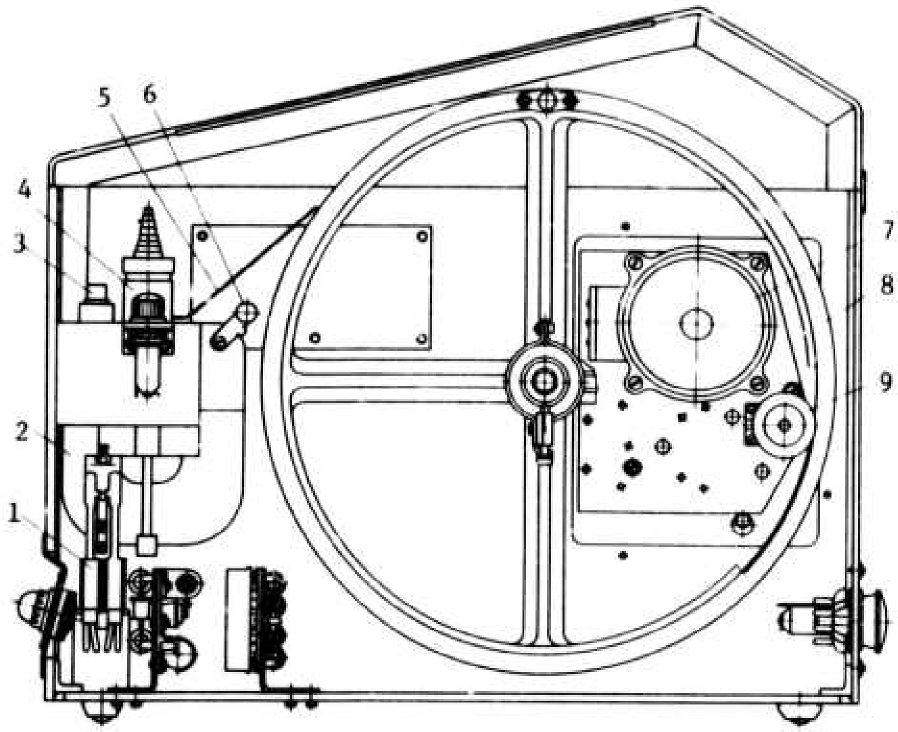


Fig. 15 -- Schematic drawing of the N-002 hot-pen recorder [19]
1 - relay
2 - magnetic system
3 - control knob for adjusting magnetic system
4 - galvanometer
5 - galvanometer pen
6 - pen-lifting lever
7 - electric motor
8 - drum
9 - rubber roller drive

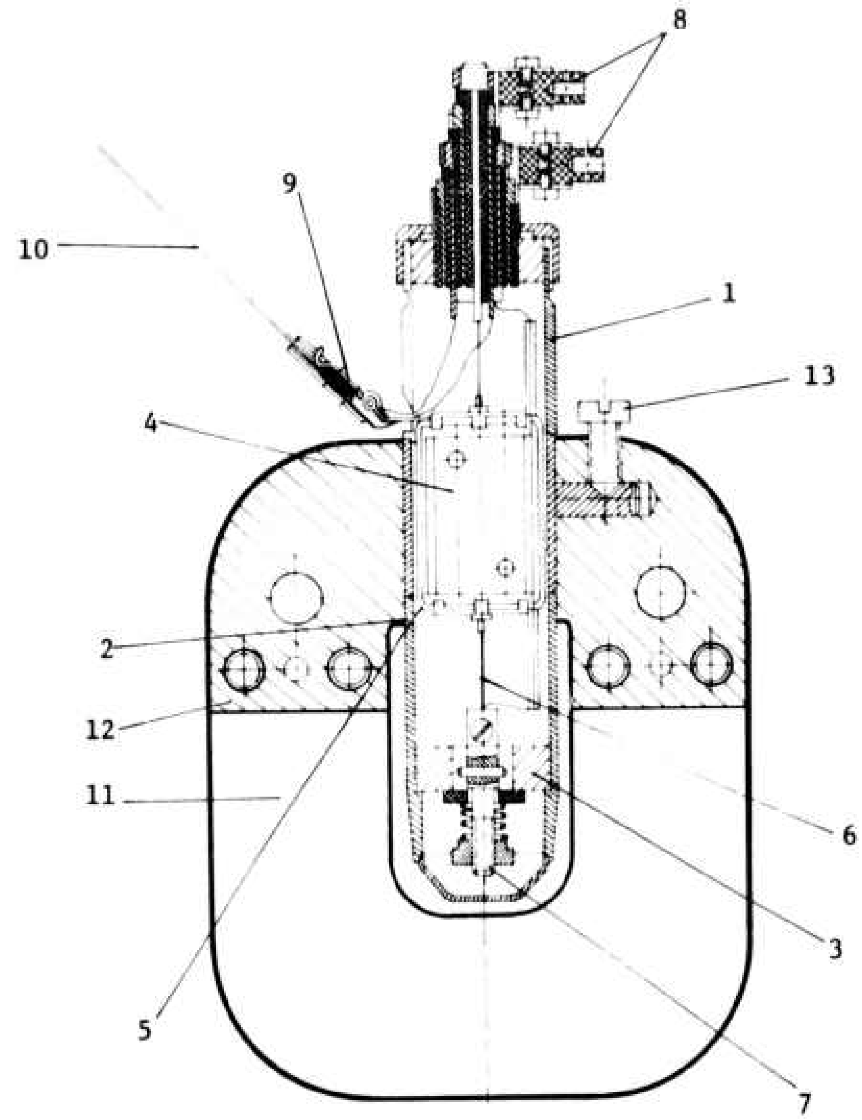


Fig. 16 -- Schematic drawing of the GPT-II galvanometer pen [20]

1 - housing
2 - lining of Armco steel
3 - insert
4 - core
5 - coil
6 - suspension
7 - screw
8 - contact cap
9 - spring
10 - pen
11 - magnet
12 - pole piece
13 - clamping screw

Frequency range	0 to 3 Hz
Maximum double amplitude	40 mm
Trace thickness	$\leq$0.5 mm
Rotation speeds	30, 60, 120, 240 mm/min
Translation rates	1.75, 3.5, 5, 10 mm/rev
Record duration	26 hrs at 30 mm/min and 1.75 mm/rev
Galvanometer pen	
Natural frequency	18 Hz
Current sensitivity	1.5 x 10^{-3} A/mm at 1 m
Voltage sensitivity	0.22 V/mm at 1 m
Coil resistance	160 x 2 ohms
Pen resistance	3 ohms
Power supply	127 or 220 V ac, 70 W
Dimensions	48 x 46 x 47 mm
Weight	38 kg

b. PST [1]. The PST three-channel hot-pen recorder (Fig. 17) is a modified model of the N-002. It records on a 30.5-cm-wide, 90-cm-long loop of heat-sensitive paper mounted on a drum driven by a synchronous electric motor. The PST is equipped with three GPT-II galvanometer pens (Fig. 16), which are also used in the N-002. Constant trace width is maintained independently of the deflection rate of the galvanometer by means of a power amplifier, which automatically adjusts the pen-heating current in proportion to the voltage fed to the pen. Time marks are printed on the heat-sensitive paper when a relay briefly disconnects the circuit between the pen and the power supply. The recorder is intended for operation at temperatures between +10°C and +40°C and relative humidity of up to 80 percent. The technical specifications of the PST are as follows:

Frequency range	0 to 3 Hz
Maximum double amplitude	20 mm
Trace thickness	$\leq$0.4 mm
Rotation speeds	30, 60, 120, 240 mm/min
Translation rates	1, 1.75, 3.5, 5 mm/rev

Record duration (three channels) .. 1 to 48 hrs

Galvanometer
  Natural frequency .... 15 to 16 Hz
  Current sensitivity .... 2×10^{-3} A/mm at 1 m

Power supply .... 127 or 220 V ac, ≤ 1 A

Dimensions .... 49 x 43.5 x 33.5 cm

Weight .... 27 kg

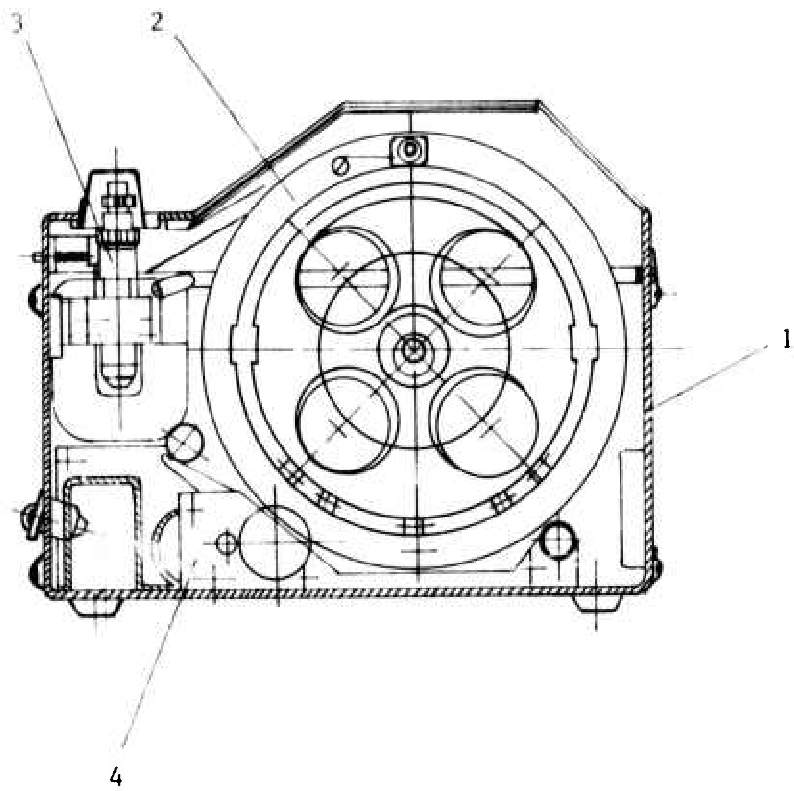


Fig. 17 -- Schematic drawing of the PST hot-pen recorder [1]
1 - housing
2 - drum with loop of heat-sensitive paper
3 - pen
4 - electric motor

c. PP-6 [20]. The PP-6 six-channel recorder, one of the earliest heated-stylus units, was developed for use in seismology and elsewhere. It records on 30-cm-wide, 50-m-long roll of heat-sensitive paper transported between supply and take-up reels by a synchronous motor without transverse motion. It has an opening through which the paper can be fed to the outside for quick processing of the seismogram. The recorder is equipped with six GPT-II galvanometer pens (Fig. 16). Constant trace width is maintained independently of the deflection rate of the pen by means of a power amplifier. Time marks from a clock are recorded along both sides of the paper. The technical specifications of the PP-6 hot-pen recorder are as follows:

Frequency range	0 to 7 Hz
Maximum double amplitude	40 mm
Trace thickness	≤0.5 mm
Rotation speeds	0.25, 0.5, 1, 2, 4 mm/sec or 4, 8, 16, 32, 64 mm/sec
Galvanometer	
Natural frequency	10 Hz
Current sensitivity	10^{-3} A/mm at 1 m
Voltage sensitivity	5 x 10^{-2} V/mm at 1 m
Coil resistance	50 ohms
Pen resistance	3 ohms
Maximum coil current	[illegible] A
Maximum pen current	0.5 A
Power supply	127 or 220 V ac, ≤1 A
Dimensions	59 x 44 x 21 cm
Weight	29 kg

d. SPR [1]. The SPR hot-pen recorder (Fig. 18), designed originally for use at seismic stations equipped with tsunami warning equipment, is presently being used with both low-gain, wide-band and high-gain, short-period seismometers. Although described as having from one to three channels, it is recommended as a one-channel recorder. It records on a loop of heat-sensitive paper of unspecified dimensions mounted on a drum. The time marks are provided from an external clock. The SPR is equipped with a 10- to 15-Hz galvanometer pen. Although the SPR can

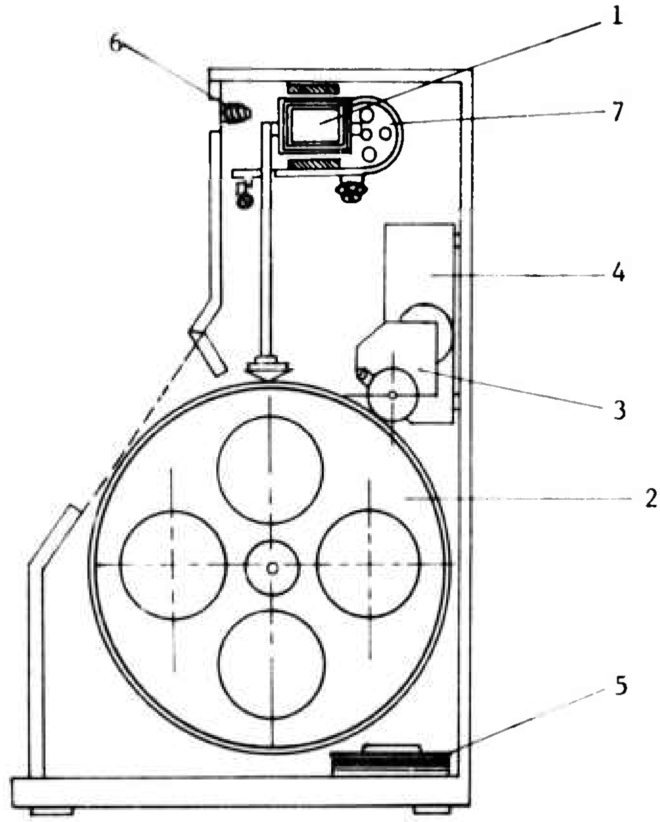


Fig. 18 -- Schematic drawing of the SPR hot-pen recorder [1]
1 - galvanometer pen
2 - drum with heat-sensitive paper
3 - motor
4 - amplifier system, timing-pulse generator, and earthquake-signal relay
5 - power transformer
6 - earthquake light-warning system
7 - earthquake sound-warning system

be operated with an internal power amplifier, it is usually used with either a UPN-3M or the IPR amplifiers. The technical specifications of the recorder are as follows:

Number of channels	1 to 3
Maximum double amplitude	100 mm
Minimum trace thickness	0.2 mm
Recording speeds	4.5, 6.0, 12, 30 mm/min
Pen translation rate	2 mm/rev
Dynamic range (one channel)	54 dB
Input impedance of power amplifier	~500 ohms
Galvanometer pen	
Natural frequency	10 to 15 Hz
Damping	Critical
Voltage sensitivity	0.2 V/mm at 1 m
Power supply	127 or 220 V ac, 10 W
Dimensions	33 x 46 x 60 cm
Weight	20 kg

4. Electrostatic Recorders

a. PEO-I [21,22,1]. The PEO-I (Fig. 19), a compact, three-to-six channel, electrostatic light-beam oscillograph, records on 120-mm-wide, plain strip-chart paper. Developed in 1969-1970, the PEO-I is apparently intended to replace similar earlier models of electrostatic recorders, such as the SEO-I, N-001 (SEO-II), and the A-002 attachment to the N-700 light-beam oscillograph; these recorders used low-sensitivity paper that required toxic developers.

The PEO-I is operated in a standby mode and actuated without a loss of motion by an unspecified electronic trigger. Its metallic drum, driven at a uniform speed by an electric motor, is covered with a layer of selenium or arsenic-selenium. The light beams reflected from the galvanometer mirrors establish electrostatic patterns of trace images on the selenium layer. When actuated, the images are automatically developed by charged dry powder, and then transferred and heat fused onto plain strip-chart paper. The developed paper is either wound on the take-up reel or fed outside for quick processing of the seismogram. The recorder is intended for operation under stationary and field conditions at temperatures between +15°C and +30°C and a relative humidity of up to 80 percent. The technical specifications of the PEO-I are as follows:

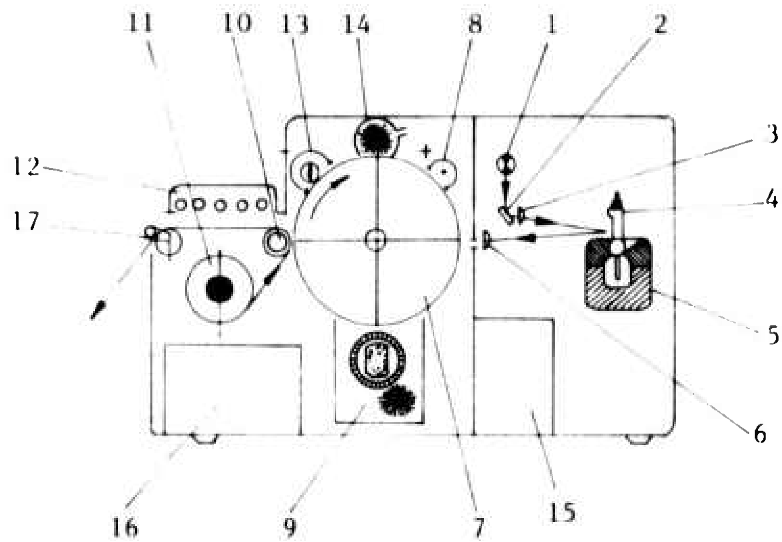


Fig. 19 -- Schematic drawing of the PEO-I electrostatic light-beam oscillograph [1]

1 - lamp
2 - mirror
3 - lens
4 - galvanometer
5 - magnet assembly
6 - lens
7 - metallic drum with layer of selenium or arsenic-selenium
8 - roller to charge the drum
9 - developing device
10 - transfer roller
11 - supply drum
12 - fusing device
13 - lamp
14 - cleaning device
15 - vacuum pump
16 - mechanical components
17 - driving roller

Number of channels	3 to 6 [1]; 6 to 12 [11]
Mode of operation	Self-actuating with no loss of motion
Frequency range	0 to 200 Hz
Maximum pen excursion	±3 cm
Optical lever	15 cm
Recording medium	Plain paper, 12 cm wide and 20 m long
Recording speed	0.75, 3, 12, 48 mm/sec [1] 4, 8, 16, 32, 64, 128 mm/sec [11]
Translation rate	0
Power supply	220 V ac, 300 W
Dimensions	50 x 30 x 30 cm
Weight	27 kg

b. ASEO-I [11]. The ASEO-I compact three-to-six channel electrostatic light-beam oscillograph, which records continuously on plain paper for a period of up to 20 days, was developed in 1973. The basic difference between the PEO-I and the ASEO-I is that the latter has transverse motion capability due to translation of either the galvanometers or the drum. The ASEO-I records continuously on up to forty 20- by 45-cm strips of paper without reloading; the strips are removed from the drum every 3, 6, or 12 hours. The technical specifications of the ASEO-I are as follows:

Channels	3 to 6
Optical lever	15 cm
Paper	40 strips, 20 x 45 cm
Recording speed	15, 30, 60, 120, 240 mm/sec
Record duration per strip	3, 6, 12 hours
Total (40 strips)	20 days
Power supply	220 V ac, 25 to 200 W

5. Magnetic-Tape Recording Systems

Soviet seismologists make little use of magnetic-tape recording and playback systems. A slow-speed, magnetic-tape-cassette recording system for ocean-bottom seismographs was developed in the early 1960s by seismologists at the Moscow State University. The cassette recorder provides 2 to 4 channels of direct recording over a frequency range of 2 to 20 Hz. The transport runs at a speed of 1.2 mm/sec, providing up to 150 hours of storage capacity on standard 6-mm tape. (Ocean-bottom seismographs are described in more detail in Section I-E-12.)

A two-track direct-tape-recording system for registration of seismic signals in the period range of 1 to 30 sec was also developed at the Moscow University. The system records at the very low speed of 0.1 mm/sec (0.004 ips) and has a dynamic range of 35 dB [23].

Direct recording on five-track 35-mm magnetic tape is used in the Zemlya system, the earliest model of which was developed in the late 1950s. The Zemlya system is used primarily for the investigation of the earth's crust and the upper mantle. The Zemlya recording speed is 1 to 3 mm/sec, the frequency range of signals is 0.5 to 20 Hz, and the dynamic range is 40 dB. The Zemlya system is described in greater detail in Section I-E-11.

The eight-track tape recorder in the Tayga system for deep seismic sounding was developed in the early 1960s. Pulse-frequency modulation is used to record explosion-generated seismic waves over the frequency range of 2 to 200 Hz at the speed of 9 cm/sec. The center frequency and percent modulation is 1.5 kHz ± 66 percent [24].

a. KSE FM-Tape-Recording System. This eight-track, slow-speed FM tape-recording system developed by the KSE (Multidiscipline Seismological Expedition) in the late 1960s consists of an operational tape recorder and a storage tape unit intended for the registration of seismic signals in the frequency range of 0.01 to 15 Hz. The electrical outputs from six signal, one timing, and one wow- and flutter-compensation channels are recorded continuously on 19-mm tape by the operational tape recorder at a transport speed of 1 cm/sec. The operational tape unit is equipped with a one-minute delay loop, which makes it possible to transfer without a loss of first motion seismic events sufficiently large to trigger the storage tape recorder. The 250-Hz carrier modulated up to 50 percent by seismometer output is converted to 125 Hz ± 50 percent to reduce crosstalk. The KSE FM tape-recording system is also discussed in connection with the Hall-effect SGKD-0 seismograph in Section II-C-11.

b. Obninsk PFM Tape-Recording System [25]. Few data are available on the pulse-frequency-modulation tape-recorder developed at the Obninsk Observatory in the early 1970s. It is a slow-speed 12-channel unit and records on 12.7-mm-wide tape. Timing is provided by an unspecified frequency signal recorded every second on one of the tracks. Another signal from the time service is employed for tape speed compensation. A multivibrator with a linearity of 0.1 percent and a stability of 0.01 percent per 1°C is used as the pulse-frequency modulator. Its output is fed into a Bessel filter and a double T RC bridge tuned to a frequency of 50 Hz.

c. Digital Tape-Recording Systems. The LMR-type digital tape recorders are used for up to 8 hours of continuous recording of seismic data in parallel on 17-track 35-mm magnetic tape at a packing density of 10 words/mm and at a tape speed of 15.5 or 150 mm/sec. The latest models, the LMR-3a and LMR-6, are designed for field and station use, respectively. The LMR-4 inputs digitally recorded seismic data into a computer at a higher tape speed. The LMR-3b tape recorder is used for transcription and visual inspection of digitally recorded seismic data acquired in the field. The LMR-6 is described in more detail in connection with KOD digital-seismograph stations in Section III-A.

d. MSh-1 and MSh-2 [26]. The only data available on the MSh-1 and MSh-2 incremental digital recording systems are their packing density, 5 words/mm, and their recording speed, up to 250 16-bit numbers per second.

E. SEISMOGRAPHS

1. SKM-3 Short-Period, High-Gain, Galvanometrically Recording Seismograph System [1,27]

The SKM-3 seismograph system, consisting of two SVKM-3 and one SGKM-3 seismometers, three GK-VIIM galvanometers, and a PS-3M recorder, is the standard short-period, high-gain set of instruments used for galvanometric registration at Soviet ESSN (Unified Seismic Observation System) seismographic stations. The four magnification sensitivity (S_x) curves shown in Fig. 20 are the recommended, standard magnification curves of such SKM-3 systems. The selection of a particular magnification curve depends on the seismic noise at the station.

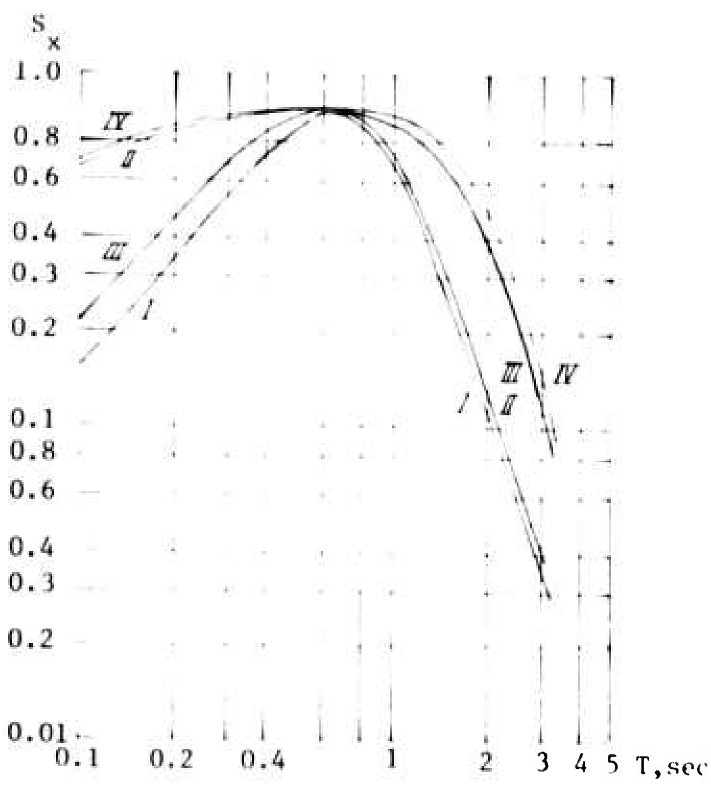


Fig. 20 -- Magnification curves of standard galvanometrically recording SKM-3 seismographs [27]

Table 3 gives the instrumental constants of SKM-3 seismographs having the magnification curves shown in Fig. 20; in the table, T_s is the seismometer period, D_s is the seismometer damping factor, T_g is the galvanometer period, D_g is the galvanometer damping factor, σ^2 is the coupling coefficient, and v_{max} is the maximum magnification. A more detailed discussion of instrumental constants, as well as numerous other standard magnification curves of photographically recording SKM-3 seismographs, appears in Part I of this Report.

Table 3 [27]

INSTRUMENTAL CONSTANTS OF SKM-3 SEISMOGRAPHS HAVING THE FREQUENCY RESPONSES SHOWN IN FIG. 20

Curve in Fig. 20	T_s (sec)	D_s	T_g (sec)	D_g	σ^2	v_{max}
I	1.24	0.490	0.580	0.495	0.0703	10^5
	1.22	0.495	0.595	0.495	0.0176	5×10^4
	1.21	0.495	0.595	0.500	0.00430	2.5×10^4
	1.20	0.500	0.600	0.500	0.00109	1.25×10^4
II	1.13	0.645	0.300	1.58	0.314	10^5
	0.94	0.545	0.360	1.90	0.0772	5×10^4
	0.91	0.510	0.375	1.97	0.0200	2.5×10^4
	0.90	0.505	0.380	1.99	0.0050	1.25×10^4
III	1.88	0.400	0.575	0.675	0.1990	10^5
	1.82	0.400	0.595	0.695	0.0484	5×10^4
	1.81	0.400	0.600	0.695	0.0121	2.5×10^4
	1.80	0.400	0.600	0.700	0.00302	1.25×10^4
IV	2.15	0.530	0.295	1.50	0.781	10^5
	1.74	0.530	0.370	1.84	0.160	5×10^4
	1.63	0.505	0.390	1.95	0.0390	2.5×10^4
	1.61	0.505	0.395	1.97	0.00968	1.25×10^4

2. Standard Short-Period, High-Gain Visual-Recording Seismograph Systems [1]

Two different standard short-period, high-gain, visual-recording seismograph systems are used at ESSN seismograph stations.

The first system, with a gain of between 20,000 and 50,000, consists of: two KS-G and one KS-V, or two SGKM-3 and one SVKM-3, short-period seismometers with T_s = 1.5 sec and D_s = 1.0; an IPR galvanometer amplifier with a parametric variable reluctance transducer, with the natural period of the galvanometer between 2 and 4 sec and a damping factor of 1.0; and an N-002, SPR, or PST heated-stylus recorder. A magnification curve of such seismograph systems is shown in Fig. 21.

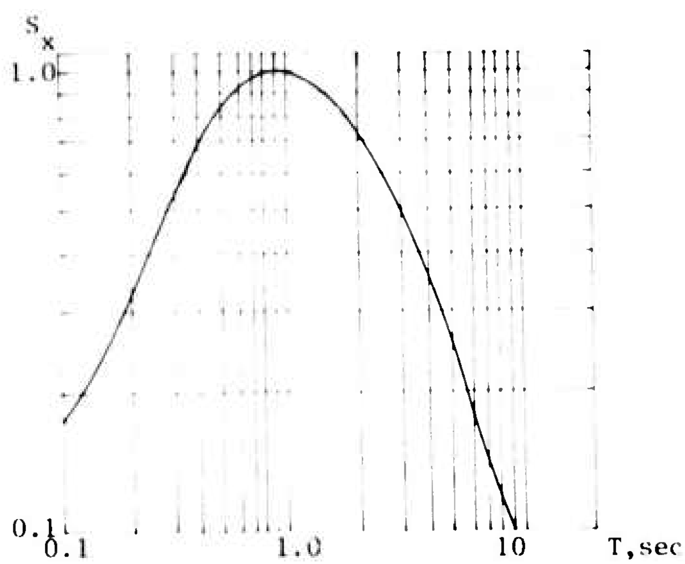


Fig. 21 -- Magnification curve of the standard short-period high-gain (v_{max} = 2 x 10^4 to 5 x 10^4) visual-recording seismograph system consisting of KS or SKM-3 seismometers, IPR amplifiers, and a heated-stylus recorder [1]

The second standard short-period, high-gain, visual-recording seismograph system, with a maximum gain between 2 x 10^5 and 2.5 x 10^5, consists of two KS-G and one KS-V, or two SGKM-3 and one SVKM-3, seismometers with T_s = 1.5 sec and D_s = 0.7 to 1.0; a UPN-3M amplifier; and an N-002, SPR, or PST heated-stylus recorder. The magnification curve of this seismograph system is the same as curve IV in Fig. 20.

3. <u>USF-3M</u> [1,2,27]

The seismograph system consisting of USF-3M seismometers, GK-VIIM galvanometers, and a PS-3M recorder could be operated at a higher gain (v_{max} = 180,000 at T = 0.6 sec) than any other galvanometrically recording instruments in use in the Soviet Union in the late 1960s. A magnification curve of two horizontal-component seismographs consisting of USF-3M seismometers, GK-VII galvanometers, and a PS-3M recorder, operated at the Novolazarevskaya station in 1969 at a maximum gain of 128,000, is shown in Fig. 22.

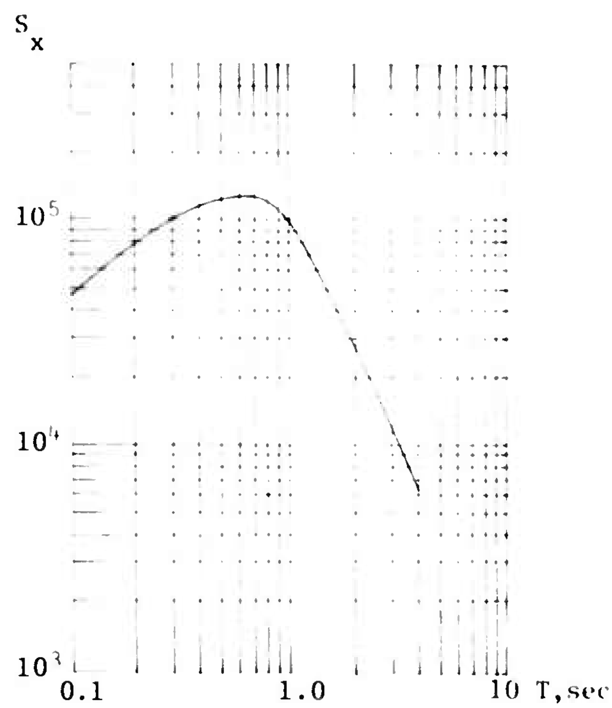


Fig. 22 -- Magnification curve of two horizontal-component USF-3M seismographs operating at the Novolazarevskaya station in 1969 [28]

T_s = 1.5 sec

D_s = 1.0

T_g = 0.54 sec

D_g = 1.0

σ^2 = 0.300

v_{max} = 128,000

The frequency responses of the standard SKM-3 seismographs shown in Fig. 20 can also be achieved with USF-3M seismometers and GK-VIIM galvanometers. Table 4 gives the instrumental constants of USF-3M seismographs with the magnification curves shown in Fig. 20.

Table 4 [27]

INSTRUMENTAL CONSTANTS OF GALVANOMETRICALLY RECORDING USF-3M SEISMOGRAPHS HAVING THE FREQUENCY RESPONSES SHOWN IN FIG. 20

Curve in Fig. 20	T_s (sec)	D_s	T_g (sec)	D_g	σ^2	v_{max}
I	1.31	0.480	0.550	0.485	0.252	10^5
	1.22	0.490	0.580	0.490	0.062	$5x10^4$
	1.21	0.495	0.595	0.495	0.015	$2.5x10^4$
	1.20	0.500	0.600	0.500	0.0050	$1.25x10^4$
II	--	--	--	--	>1	10^5
	1.07	0.625	0.320	1.67	0.253	$5x10^4$
	0.93	0.540	0.365	1.91	0.064	$2.5x10^4$
	0.91	0.515	0.375	1.97	0.0167	$1.25x10^4$
III	2.02	0.395	0.535	0.750	0.612	10^5
	1.87	0.400	0.580	0.670	0.170	$5x10^4$
	1.82	0.400	0.595	0.690	0.411	$2.5x10^4$
	1.81	0.400	0.600	0.695	0.0102	$1.25x10^4$
IV	--	--	--	--	>1	10^5
	2.10	0.535	0.305	1.53	0.65	$5x10^4$
	1.72	0.530	0.370	1.86	0.137	$2.5x10^4$
	1.63	0.510	0.390	1.97	0.0332	$1.25x10^4$

The USF-3M seismometers are also used with the DFU phototube galvanometer amplifiers and the EPP-09 visual recorder.*

*No data are available on the EPP-09 recorder.

4. USF-4

The USF-4 short-period, high-gain seismograph can be used with photographic, visual, and magnetic-tape recording systems, and can be operated at higher gain than any other Soviet short-to-intermediate-period instrument, with the exception of the SBU-V vertical-component borehole seismograph. No further data, other than the description in Section I-A-4, are available on the USF-4.

5. VEGIK

Developed originally as a strong-motion instrument, the VEGIK seismometer has found its main application in engineering seismology, microseismic measurements, and seismology. When used in engineering seismology it is coupled with portable light-beam oscillographs; for seismic applications, mostly at regional and expeditionary seismographic stations, it is used with the PS-3M recorder operated at speeds of 120 to 240 mm/min. The nominal values of the instrumental constants of VEGIK instruments used at regional and expeditionary stations for the registration of earthquakes are: T_s = 0.7 to 1.0 sec, D_s = 0.4 to 0.5, T_g = 0.065 to 0.10 sec, D_g = 2 to 3, σ^2 = 0.1 to 0.4, v_{max} = 20,000 to 25,000. Several standard VEGIK magnification curves are shown in Part I of this Report.

6. SM-2M and SM-3

Few data are available on the SM-2M and SM-3 seismographs. The instrumental constants of an engineering system consisting of an SM-2M seismometer and an OSB-IMp light-beam oscillograph with GB-IV galvanometers are [29]: T_s = 1.5 sec, D_s = 0.6, T_g = 0.2 sec, D_g = 5, $\bar{v}$ (normal magnification) = 13,000, and T_m = 0.03 to 1.0. The magnification curve (not given) should be similar to that of the VEGIK seismograph.

The magnification curve of a high-gain system consisting of an SM-2M seismometer with T_s = 1 sec, an amplifying system including an integrating circuit, and an unspecified photographic recorder with GB-IV galvanometers (T_g = 0.07 sec) is shown in Fig. 23 [30].

The magnification curve of the SM-3 should differ little from that of the SM-2M.

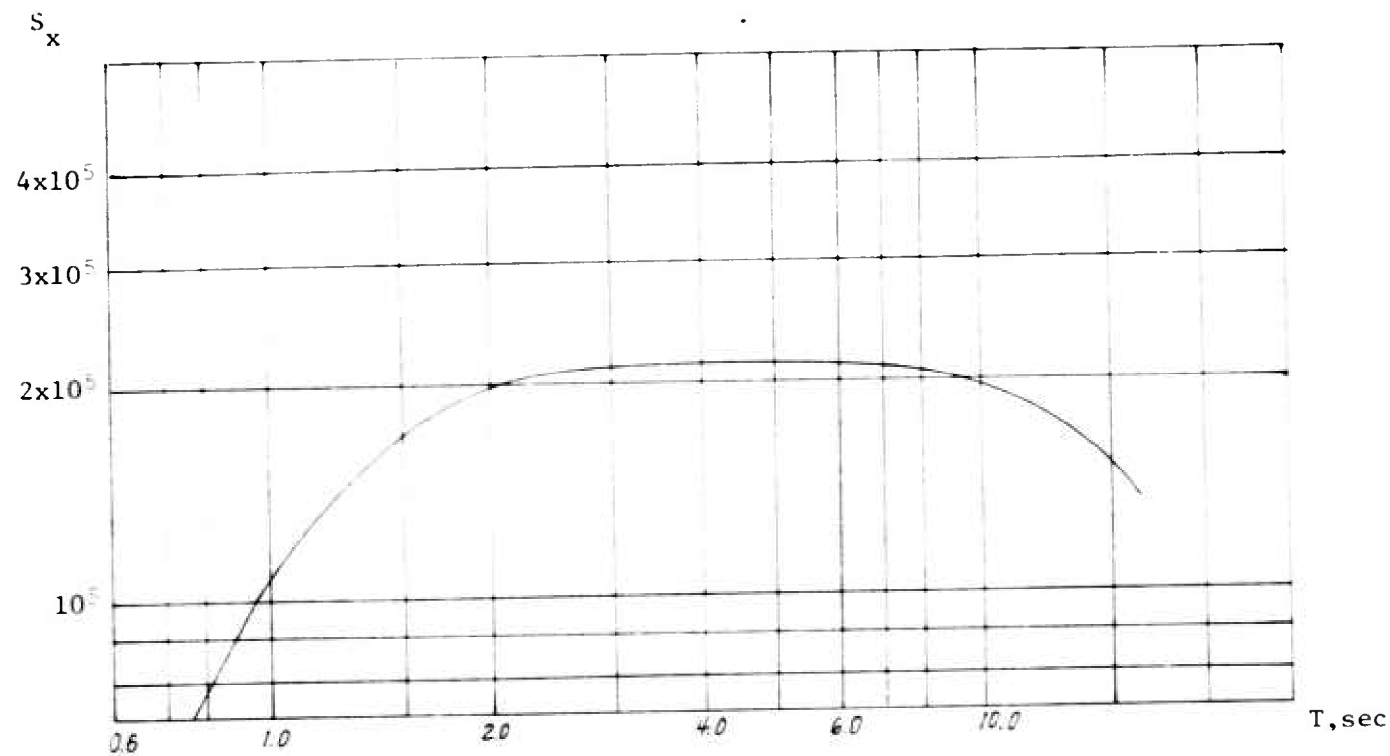


Fig. 23 -- Magnification curve of a high-gain seismograph system consisting of an SM-2M seismometer, an unspecified amplifier, and an unspecified light-beam oscillograph with GB-IV galvanometers [30]

7. S5S [31]

Although the S5S is usually used in strong-motion systems for the registration of earthquakes of intensity III to VIII, the seismometer is also frequently coupled with an amplifier and a visual recorder resulting in a medium-gain, intermediate-period system. The magnification curve of one such system consisting of an S5S seismometer, a UPN-3 amplifier, and N-002 hot-pen recorder is shown in Fig. 24. The period of the recording galvanometer pen is 0.08 sec.

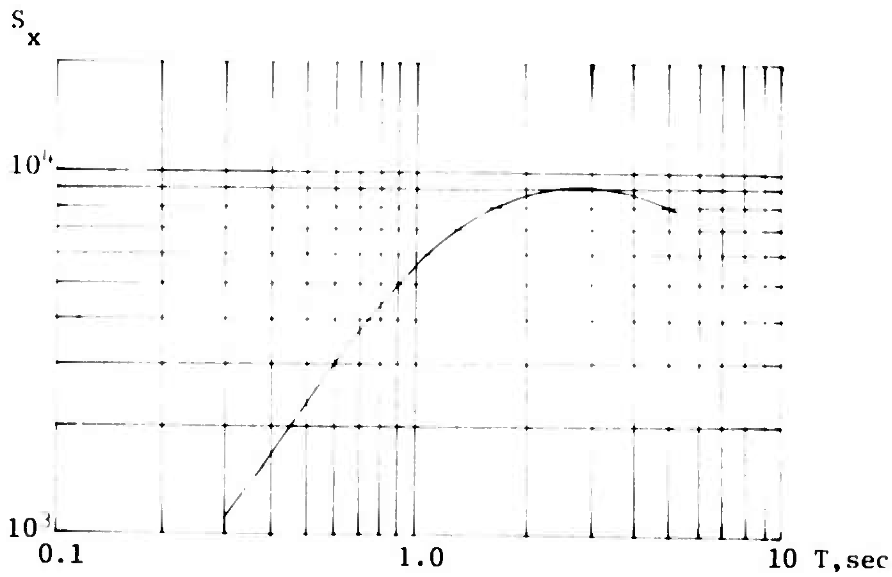


Fig. 24 -- Magnification curve of a seismograph consisting of a S5S seismometer, UPN-3 amplifier, and a N-002 heated-stylus recorder [31]

$T_s = 5$ sec

$D_s = 1.5$

$V_{max} \approx 9200$

8. Solion Seismograph [32,33]

A solion seismograph, based on the principle of oxidation-reduction of electrolyte, was developed in the late 1960s.* The time frame of the

---

*Soviet seismologists were apparently unaware of the solion seismometers developed and tested in the United States in the early 1960s.

solion short-period, three-component displacement seismometer consists of a hollow fluoroplastic cylinder with two elastic membranes made of chemically stable rubber stretched across its ends. A partition with an opening at its center and with its plane perpendicular to the cylinder's axis of rotation divides the cylinder into two equal chambers. Platinum grid electrodes are located within the opening of the partition and parallel to its plane. The cylinder is filled with a solution of potassium iodide with a small amount of iodine. The electrodes and the electrolyte form an oxidation-reduction system. A potential difference of 0.6 V dc across the electrodes generates a dc current in the circuit; in the absence of mechanical vibrations, the current reduces the iodine molecules at the cathode to negatively charged iodide ions; the reverse process occurs at the anode. Before the voltage is applied, the concentration of iodine molecules in the electrolyte is completely uniform. The dc current depletes the number of iodine molecules near the cathode, and this loss is only partially compensated by the diffusion of iodine from the electrolyte. Outside mechanical vibrations induce oscillations of the frame and electrodes relative to the electrolyte, resulting in variation in the concentration of iodine molecules near the cathode and the appearance of an ac component of current. The frequency and amplitude of the ac signal is proportional to the frequency and amplitude of forced oscillations.

The natural frequency of a solion seismometer depends on the mass of the electrolyte, the rigidity of the membrane, and the construction of the seismometer. For example, increasing the length of the channel (opening) connecting the two chambers will increase the natural period of the seismometer by as much as five times its value in the absence of an opening, i.e., in the presence of a semipermeable partition only. Further increase in natural period can be achieved by increasing the ratio of the cross-sectional areas of the chambers to that of the channel. The length and diameter of a number of experimental solion seismometers varied between 4 to 15 cm and 3 to 5 cm, respectively, and their weight was between 70 and 200 grams.

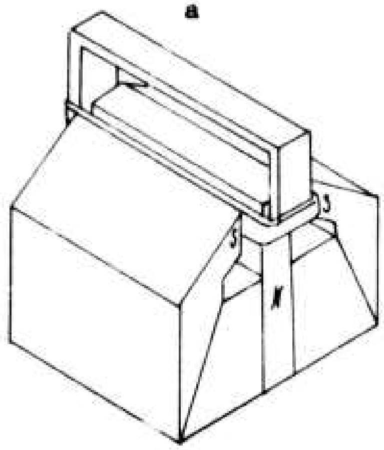
Shake table experiments in the frequency range of 0.1 to 10 Hz have shown that the sensitivity of solion seismometers at a frequency of 1 Hz was 1 to 1.5 mV/μm, or an order of magnitude greater than that of the short-period VEGIK seismometer. The frequency-response curve of a solion seismometer displays a point of inflection at 1 Hz, increasing almost proportionally to frequency up to f = 10 Hz and decreasing proportionally to the square of the frequency down to f = 0.1 Hz. Field tests have shown the suitability of solion seismometers as short-period surface and deep-borehole seismographs for the registration of both earthquakes and explosions.

It is claimed that the instrument noise of the solion seismograph was below the level of microseismic noise in relatively quiet areas such as the Talgar underground observatory and a 1500-m-deep borehole.

9. ASS Continuously Recording, Three-Component Displacement Seismograph System for Unattended Operation [1,34]

The ASS is a short-period, three-component seismograph system designed for continuous, unattended, galvanometric recording of displacements for a period of up to one month. The ASS system consists of five hermetically sealed packages: (a) a three-component seismometer assembly unit, (b) two identical microrecording units, (c) a timing unit, and (d) a power supply unit.

The seismometer assembly unit has three pendulum-type, moving-coil seismometers with electromagnetic damping. The magnet-coil assembly of each transducer (Fig. 25a) consists of two permanent magnets and three pole pieces which form two air gaps that extend parallel to the pendulums' plane of oscillation. The coil is formed by wire wound on the two longer sides of a rectangular coil-former, which fits over the center pole-piece. The signal coil sensitivity of each seismometer at a coil resistance of 800 ohms is 180 V/(m/sec). The axes of rotation of the pendulums are formed by two pairs of crossed steel hinges. The installation of seismometers at a site requires carefully aligning the rotation axis of the horizontal pendulums with the vertical. The vertical seismometer is equipped with a zero-length spring, a manual period-adjustment a



b

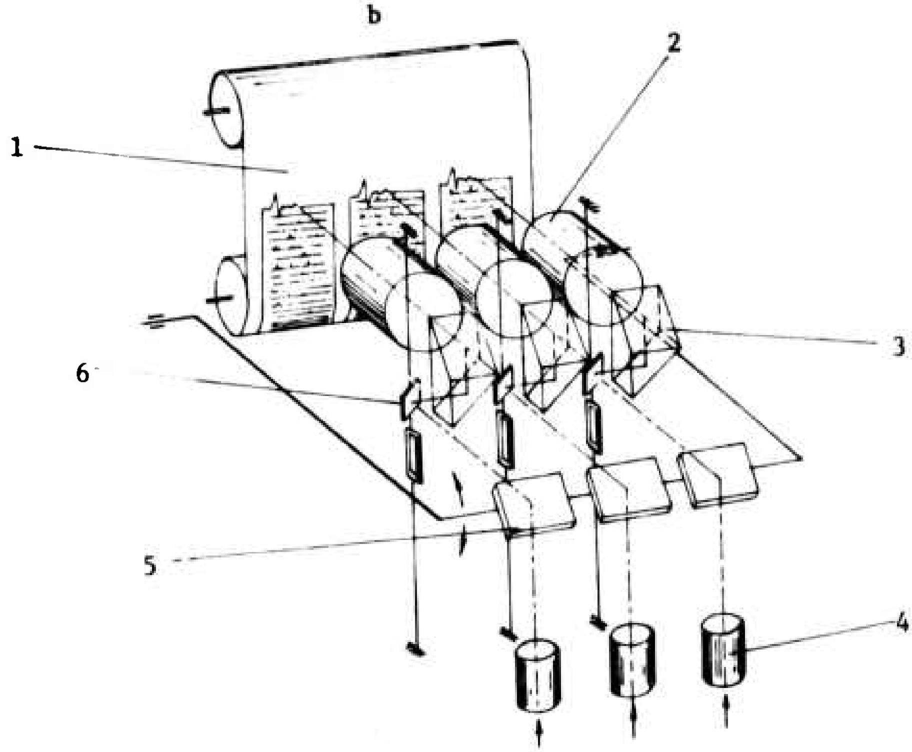


Fig. 25 -- Magnetic system of the ASS transducer (a) and the microphotorecording assembly (b) [35]
1 - film
2 - cylindrical lens
3 - prism
4 - cylindrical lens
5 - mirror on the mirror sweep assembly
6 - galvanometer mirror

control and an automatic pendulum-equilibrium adjustment device which operates, when needed, twice a day.

Each of the two identical microrecording units, operated at different gains includes: (a) a microphotorecording assembly with three d'Arsonval galvanometers, (b) a film cassette, (c) an electrically wound chronometer, and (d) a special device for hourly recording of date and time code numbers. The microphotorecording assembly (Fig. 25b) operates in the following way. Three parallel beams of light reflected by the three mirrors of the mirror-sweep subassembly, are reflected again by the three galvanometer mirrors and focused onto stationary, high-resolution (250 lines/min), 70-mm photographic film. The rotation of the mirror-sweep subassembly causes the three light beams to be recorded along the width rather than the length of a stationary photographic film. Although it has no effect on the constant rotation speed of the mirror-sweep subassembly, ground motion induces to-and-fro movement of the galvanometer mirrors. Since the axes of rotation of the galvanometer mirrors and the mirror-sweep subassembly are perpendicular to each other, the three components of displacement are recorded along the length of the film and perpendicular to the lines recorded in the absence of ground motion. When the light beams reach the edge of the film, i.e., when the mirror-scan subassembly rotates through an angle of 10°18', the mirror-scan subassembly rapidly (≤ 0.1 sec) returns to its initial position and simultaneously advances the film a specific distance.

The mirror-sweep subassembly is driven by a specially designed low-power dc motor* that has neither brushes nor commutators and is operated by a battery switched on by three photodiodes. The speed of the motor is controlled by a centripetal device consisting of three shutters equipped with springs.

The minute marks from a self-winding GMKh chronometer are printed on the record in the form of dots. Every hour a special device prints between the traces in code the year, month, day, hours, serial number of the microphotorecording assembly, and channel number. A one-second

---

*Described in C. Shishkevish, *Soviet Strong-Motion and Vibration-and-Blast Seismographs*, The Rand Corporation, R-1652-ARPA, Section IV-P.

gap denotes the beginning of the hour. Radio transmitted precision time marks with an accuracy of 0.1 sec are automatically switched on and recorded twice a day.

Depending on the film transport mechanism used in the cassette, the trace spacing on the film can be either 0.3, 0.6, or 6 mm. The recording speed is 3.6 or 7.2 mm/min. A viewer enlarges the image by a factor of $16\frac{2}{3}$ and increases the trace spacing to 5, 10, or 100 mm and the recording speed at the viewer to 60 or 120 mm/min. Depending on the trace spacing and the recording speed the ASS system can record continuously 5.5, 11, 55, 110, and 220 days.

The weight of each package does not exceed 60 kg and the weight of the whole system is 180 kg.

The technical specifications of the ASS system are as follows:

Seismometers

Natural period	1.7 to 2.1 sec
Moment of inertia	0.05 kg·m^2 ± 20%
Reduced length	0.1 m ± 20%
Signal-coil sensitivity	180 V/(m/sec) ± 20%
Coil resistance	800 ohms ± 10%

Microphotorecording Assembly

Galvanometers	
Natural period	0.55 sec ± 20%
Moment of inertia	10^{-10} kg·m^2 ± 20%
Voltage sensitivity	8 x 10^{-6} V/m at 1 m ± 20%
Coil resistance	130 ohms ± 10%
External critical resistance ...	2400 ohms ± 20%
Recording medium	Photographic film, 70 mm wide, 20 m long, resolution of 250 lines/mm
Power supply	12 V dc, 56 cell battery

The design of the ASS system makes it possible to vary the maximum magnification and to adjust the shape of the displacement sensitivity curve of each of its three components. The maximum gain of the ASS system with magnification curve IV in Fig. 20 is 3000 (50,000 at the viewer). According to [34], maximum gain of the system is ~4800 (~80,000 at the viewer).

10. SBU-V Vertical-Component Borehole Seismograph [1]

The SBU-V, a high-sensitivity borehole seismograph with a moving-coil, pendulum seismometer, is intended for the galvanometric registration of the vertical component of displacement at a maximum gain of 10^6. It consists of a ground-control panel, a three-conductor logging cable, and an hermetically sealed, cylindrical borehole package designed for operation in a five-inch borehole at a depth not exceeding 1500 m. Two signal coils above and below the pendulum, rigidly connected to it by means of levers, are located within the annular radial gaps of two stationary magnet assemblies. The axis rotation of the pendulum is formed by two pairs of crossed flat springs. The upper end of the zero-length spring is hinged to the pendulum-centering motor attached to the seismometer frame; the lower end of the spring is attached to the pendulum in such a way that the axis of rotation of the pendulum and its center of gravity lie in the same horizontal plane. The natural period of the seismometer can be adjusted manually by moving horizontally the hinge connecting the upper end of the zero-length spring to the centering motor. A photoelectric assembly switched on and off by a signal from the control panel monitors the position of the pendulum. When necessary, it automatically activates the centering motor, which adjusts the zero-length spring by moving the hinge vertically until the pendulum reaches an equilibrium position, centering the signal coils in the air gaps of the magnets. The centering motor can also be turned on and off from the control panel. The SBU-V seismometer is damped by means of shunt resistances across the coils connected into the circuit at the control panel. The natural period of the seismometer can be measured and its operation can be checked out from the control panel. Figure 26 shows a magnification curve of the SBU-V. The technical specifications of the SBU-V seismometer are as follows:

Natural period	0.8 to 1.2 sec
Reduced length	0.11 m
Moment of inertia	0.007 kg·m^2
Signal-coil sensitivity	136 V/(m/sec)
Signal-coil resistance	600 ohms
Maximum allowable pressure	200 atm

Dimensions
  length .... 1.78 m
  diameter .... 0.1 m

Weight .... 43 kg

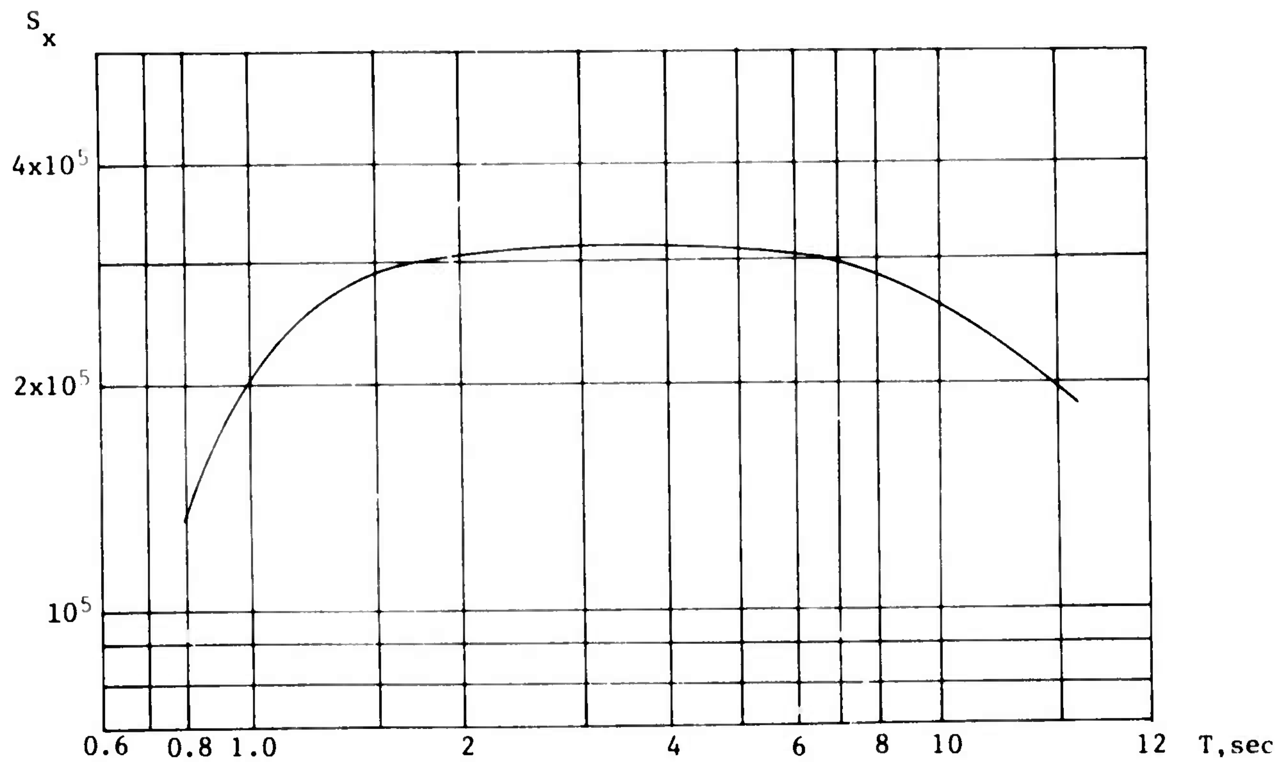


Fig. 26 -- Magnification curve of the SBU-V vertical-component seismograph consisting of a SBU-V seismometer (T_s = 1 sec) coupled with an unspecified amplifier and an unspecified light-beam oscillograph with GB-IV galvanometers (T_g = 0.07 sec) [30]

11. The Zemlya System [36 to 39]

The Zemlya system consists of a group of up to several dozen sets of three-component, short-period seismometers,* a tape recorder for each set of seismometers, a time receiver, a playback system at a central facility,

---

*When three seismometers are used, the vertical transducer is operated at two different gains. Four seismometers are also used, with the extra horizontal transducer oriented in the direction of interest.

and auxiliary equipment. Although Zemlya systems are deployed primarily in crustal and upper mantle investigations by means of converted waves, they are also used to acquire seismic data for seismological research and are suited for detection and identification of nuclear explosions. Most Zemlya systems are equipped with VEGIK seismometers. The sensitivity of later models was doubled by replacing the magnet assembly of the VEGIK with that of the USF-3M seismometer (see Section I-A-5 and I-A-3). The technical specifications of the Zemlya system are as follows:

Number of signal channels	4
Transducers	VEGIK or USF-3M
Recording system	
Recording medium	35-mm magnetic tape
Modulation type	direct with signal compression
Number of channels	4 signal, 1 timing
Tape speed	recording - 1.25 to 3 mm/sec playback - 30 to 150 mm/sec
Maximum gain	10^6
Dynamic range	40 dB
Recording time	70 to 80 hrs of continuous recording
Timing marks	sec, min, hr time marks from a chronometer or a quartz clock; hr marks from radio receiver

The playback system rerecords from magnetic tape on photographic paper at speeds up to more than 100 times the recording speed. During playback, the signal can be shaped by as many as 20 band-pass filters with the high-frequency roll-off of 12, 16, 24, or 32 dB/octave. The system is usually transported by truck or helicopter, but its exact dimensions are not known. The Zemlya system is capable of recording P, S, PS, SP, R, and other phases at distances up to 14,000 km. It can be used to detect 2- to 3-ton chemical explosions fired at distances of up to 400 km. Unspecified techniques are used to extract signals when the signal-to-noise ratio is $\geq$ -10 dB.

The Zemlya systems used in deep seismic sounding are known to be defective due to poor workmanship, poor quality of components, and certain design flaws. The major deficiencies of the system, according to [39], are (1) unstable operation and unreliability of the tape transport mechanism, (2) unreliable time receiver and chronometer, (3) the lack of a visual recorder with a playback system, (4) the low sensitivity and shielding of amplifiers in the playback system, (5) the temperature instability of the seismometers, and (6) the uneconomical power supply.

12. Ocean-Bottom Seismographs [40 to 43]

The DS-1-F vertical-component, ocean-bottom seismograph was developed in the early 1960s at the Moscow State University. The seismometer is an NS-3 geophone with a generator constant of 40 to 60 V/(m/sec) and a natural frequency of 3 Hz, modified by adding a damping coil and replacing the 320-ohm signal coil with a 1000-ohm coil. The gimbal-suspended seismometer is coupled to a transistorized UBN-1 amplifier and a low-pass filter. The gain of the UBN-1 amplifier is 10^4, and its internal noise at the input is less than 0.5 μV. The unmodulated signal is recorded on one of the two tracks of a 6.3-mm magnetic tape at a speed of 1.2 mm/sec. In the late 1960s, the tape speed of the DS-1-F was decreased to 1 mm/sec, thus increasing its recording capacity from 48 to 150 hours. Time marks from the 6-MKh chronometer are recorded on the second track of the tape. The tape transport is mounted on a separate suspension. The dynamic range of the DS-1-F is 40 dB. (A later model, the DS-2-F vertical-component ocean-bottom seismograph, has a 60-dB dynamic range.) The shape of the DS-1-F magnification curve (Fig. 27) was dictated by the seismographs' earlier intended use in deep seismic sounding, which requires undistorted registration of direct water waves.

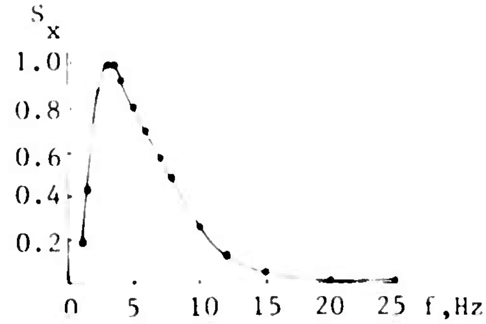


Fig. 27 -- Magnification curve of the DS-1-F vertical-component ocean-bottom seismograph [40]

The seismograph is housed in a sealed steel cylinder with an inside diameter of 20 cm. The thickness of the container wall (t) is calculated from the following empirical formula:

$$t = \frac{Pd}{2.3\ (\sigma_{max} - P)},$$

where σ_{max} is the maximum allowable stress, P is the water pressure exerted on the container, and d is its inner diameter. The operational depth capacity of the DS-1-F ocean-bottom seismograph is not known. (In its earlier applications for deep seismic sounding in the Black Sea, the seismograph was housed in a commercial-steel gas bottle and was operated at a maximum depth of 2200 m.) The DS-1-F, including dry-cell batteries and the steel gas bottle, weighs 80 kg. The seismograph is lowered to the ocean bottom on a steel cable (see Fig. 28), requiring 50 to 60 minutes for installation at a depth of 2200 m.

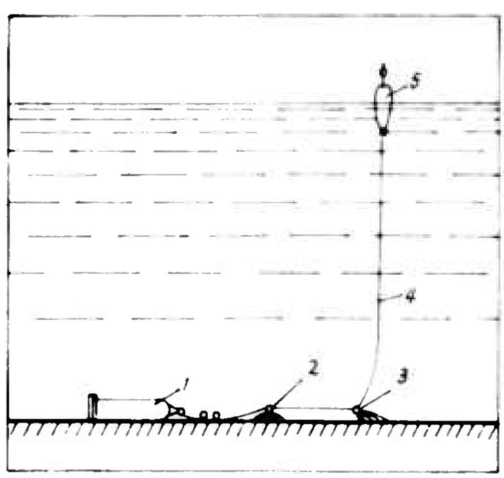


Fig. 28 -- DS-1-F seismograph installed on the ocean bottom [40]
1 - seismograph
2 - first weight
3 - second weight
4 - steel cable
5 - buoy

Table 5 gives the technical specifications of the DS-1-F and DS-2-F, as well as the DSS-1-F three-component ocean-bottom seismograph. No further data are available on the DSS-1-F.

Table 5 [43]

TECHNICAL SPECIFICATIONS OF SOVIET OCEAN-BOTTOM SEISMOGRAPHS

Design	Frequency Range (Hz)	Dynamic Range (dB)	Recording Capacity (hrs)	Power Requirement (watts)	Weight (kg)
DS-1-F	2-20	40	150	0.5	80
DS-2-F	2-20	60	150	0.5	80
DSS-1-F	2-20	40	100	0.8	130

II. LONG-PERIOD SEISMIC INSTRUMENTS

A. GALVANOMETERS

1. SPG-4a and Modified SPG-4a

In the early 1960s, East Germany agreed to develop according to Soviet specifications a long-period galvanometer for possible use in Soviet long-period instruments similar to the Press-Ewing seismographs. The result was the SPG-4, a long-period galvanometer, developed in 1963. The later-model SPG-4a, improved by adding a magnetic shunt and changing some of the SPG-4 characteristics, was tested in the Soviet Union in 1965-1966 and was found to be acceptable [44]. In the late 1960s, the Soviet Union purchased 120 SPG-4a galvanometers to use with standard SD-1 long-period seismograph systems, which they plan to install at all base and some regional seismographic stations [45].

Table 6 gives the technical specifications of SPG-4a galvanometers, as determined by Soviet seismologists, and of other recent SPG and DG galvanometers. In this table, T_g is the galvanometer period; D_{go} is open-circuit damping; R_g is coil resistance; CDRX is the external critical damping resistance; C_i is the current sensitivity; and K_g is the moment of inertia.

The coil of the SPG-4a, made of 0.25-mm diameter nonmagnetic copper wire, is suspended in the air gap of a magnet by a quartz fibre of low torsion constant, approximately 5 μm in diameter. Electrical connection to the coil was through two gold ribbons, 0.2 to 0.5 μm thick, glued to the bottom coil tabs. The coil is protected by a brass cover. The dimensions of the SPG-4a are 20 x 20 x 23 cm, and it weighs about 3 kg. The galvanometer is intended for operation at seismographic stations, at temperatures between 0°C and 30°C and a relative humidity of up to 90 percent [46].

A number of undesirable characteristics were revealed when the SPG-4a galvanometers were used with SD-1 long-period seismographs. For example, the diameter of the quartz suspension fibre of the SPG-4a

Table 6

TECHNICAL SPECIFICATIONS OF SOVIET DG AND EAST GERMAN SPG LONG-PERIOD GALVANOMETERS*

Specification	SPG-4a [46]	SPG-4aM [46]	DG-100 [47]	DG-100I [47]	SPG-7a [48]	DG-200 [49]	SPG-5 [50]	DG-300 [51]	DG-300M [47]	SPG-7 [50]	DG-500 [52]
T_g (sec)	83	105	100	100	103	180	188	330	300	322	500
D_{go}	0.31	0.31	0.17	0.17	0.155	0.26	0.12	0.35	0.4	0 165	0.53
R_g (ohms)	63	40	60	70	190	75	70	75	70	190	95
CDRX (ohms)	280	390	100	2400	1035	1150	524	5500	1700	940	1450
$C_i \times 10^{-11}$ (A/mm at 1 m)	26	16	10	5	8.15	5.7	4.6	1.2	1.5	2.88	0.53
K_g ($gm \cdot cm^2$)	2.6	2.6	1.8	1.8	2.1	5.4	2.08	5.4	2	7.2	5.3

*With the shunt out.

varied between 4 and 7 μm, resulting in variation of the galvanometer period from 74 to 81 sec. Poor contact between the gold ribbons and bottom coil tabs caused breaks in electrical connection to the coil. The electrical resistance of the gold ribbons differed from one galvanometer to another causing variation of the coil resistance from 55 to 73 ohms. The brass cover over the coil was apparently responsible for the appearance of noise caused by barometric pressure variations with periods close to the natural period of the galvanometer. The cover also decreased the dimensions of the air gap, resulting in higher air damping [46].

Soviet seismologists improved the performance of the SPG-4a galvanometers by introducing the following modifications. The quartz suspension fibre was replaced with a beryllium bronze ribbon with a torsion constant of 10^{-5} gm·cm/90°, used in the DG-100 galvanometers. This increased the galvanometer period from an average of 83 sec to 105 sec, and provided an additional electrical connection to the coil, making it possible to use a single bottom gold ribbon. Better contact was achieved by soldering rather than gluing the ribbon to the bottom coil tab. Removal of the brass cover over the coil resulted in the disappearance of noise due to barometric pressure variations and, by increasing somewhat the dimensions of the air gap, caused by decrease of up to 30 percent in air resistance [46]. The technical specifications of the SPG-4a galvanometer modified by Soviet seismologists, the SPG-4aM, are given in Table 6.

2. DG Series

Between 1967 and 1970, Soviet seismologists developed the DG series (see Table 6) of excellent long-period galvanometers, including the DG-100 (T_g = 100 sec), DG-200 (T_g = 180 sec), DG-300 ($T_g \simeq$ 300 to 330 sec), and DG-500 (T_g = 500 sec). Two desirable characteristics of these galvanometers are their low open-circuit damping, which eliminates the need for a partial vacuum, and the high ratio of coil resistance with external critical resistance, which makes it possible to integrate electrical signals generated by the transducer.

The operation of the galvanometer in air was made possible by designing the coil assembly of the galvanometers in accordance with an empirical formula for air damping of a coil as a function of its geometry and its dynamic constants derived in [53].

Except for the coil assembly, all DG galvanometers are identical. A schematic drawing of a DG galvanometer is shown in Fig. 29. The galvanometer (see Fig. 29) is mounted on three adjustable legs equipped with leveling screws. The coil is suspended from the upright, and the coil assembly is enclosed under two covers. Insertion or withdrawal of the magnetic shunt varies the flux density over a wide range without affecting the homogeneity of the magnetic field. The principal parts of the magnetic shunt are two plates made of a soft magnetic material fitted into special slots of the magnet assembly, the position of which can be changed by the magnetic-shunt screw. A screw holds the coil assembly to prevent damage during transportation. The zero adjusting knob sets the coil assembly to its zero position. Provision is made for a slight adjustment of the galvanometer period. A plug socket and a ground terminal are located in the back of the galvanometer [49].

The coil of the DG is made of nonmagnetic copper (diameter not specified). The electrical connection to the coil is through the BrB_2 top suspension and the gold ribbon soldered to the bottom coil tab. In the DG-100 galvanometers, the torsion constant of the top suspension is 10^{-5} gm·cm/90° and the thickness of the bottom gold ribbon is 0.3 to 0.4 μm. In the DG-300 and DG-500 galvanometers, the torsion constant of the 10-cm-long top suspension is 10^{-6} gm·cm/90°. The 6-cm^2 coil is suspended in the air gap of the magnet, with a maximum field strength of 900 G [54].

The DG galvanometers are approximately 11.5 cm wide and 35 cm high, and weigh about 6 kg. They are intended for operation at seismograph stations at temperatures between 0°C and 30°C and a relative humidity of up to 90 percent [1].

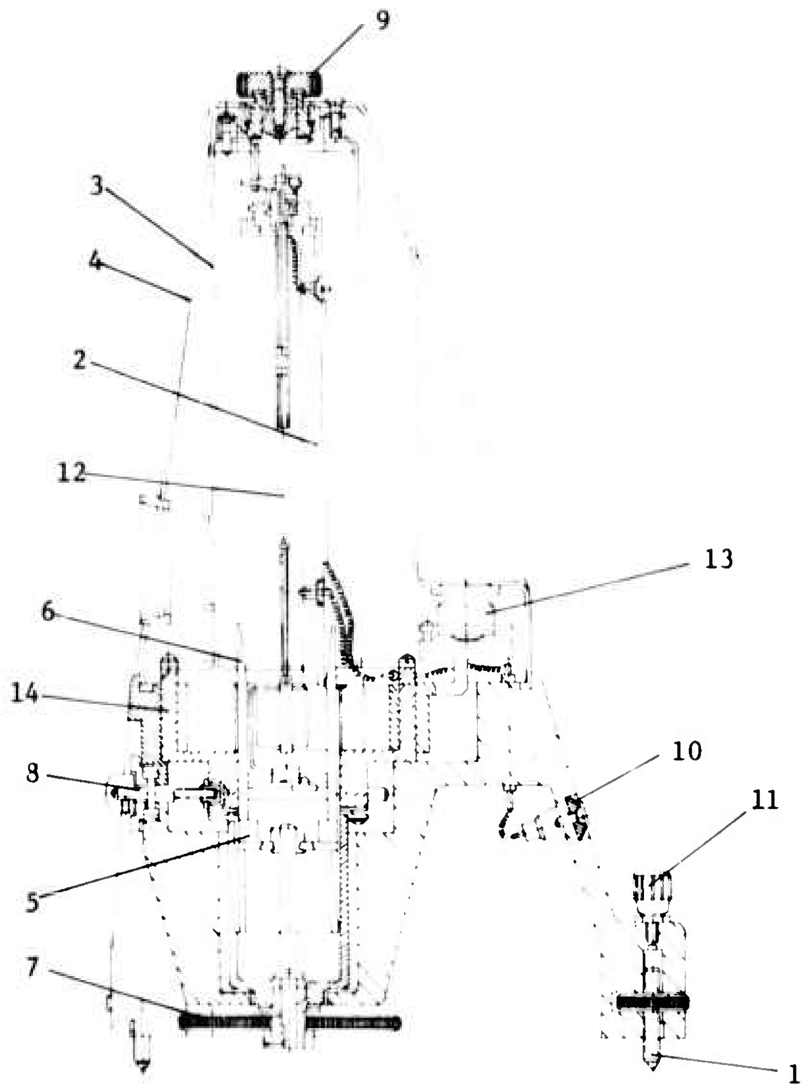


Fig. 29 -- Schematic section of a DG long-period galvanometer [49]
1 - adjustable leg
2 - upright
3 - inner cover
4 - outer cover
5 - magnetic shunt
6 - magnetic-shunt plate
7 - magnetic-shunt adjusting screw
8 - clamp screw
9 - zero adjusting knob
10 - plug socket
11 - ground terminal
12 - suspension and coil assembly
13 - bubble level
14 - magnet assembly

B. SEISMOMETERS

1. SKD and SKD-O [1,55]

The SKD (Fig. 30) are standard, widely used, long-period seismometers with electromagnetic damping, intended primarily for galvanometric recording of the vertical and horizontal components of displacement with amplitudes between 1 μm and 5 mm in the period range 0.5 and 50 to 60 sec. Both the horizontal (SGKD) and the vertical (SVKD) seismometers are pendulum instruments equipped with a moving-coil transducer. The signal, damping, and calibration coils are wound on the same nonmagnetic plate placed in the air gap of a stationary permanent magnet. The magnetic field strength in the air gap can be varied between 1800 G and 3000 G by means of a magnetic shunt. The vertical seismometer is equipped with a zero-length spring. The natural period of SKD seismometers is adjustable between 7 and 40 sec.

SKD seismometers are intended for operation at seismograph stations at temperatures between -20°C and +40°C and a relative humidity of up to 90 percent. The technical specifications of the SKD seismometers are as follows:

Natural period	25 sec (nominal)
Reduced length	0.5 m
Signal coil sensitivity	2 to 3 V/(m/sec)
Damping coil sensitivity	3 to 4 V/(m/sec)
Signal coil resistance	18 to 25 ohms
Damping coil resistance	24 to 25 ohms
Moment of inertia	0.35 kg·m^2
Dimensions	70 x 38 x 30 cm
Weight	
Vertical seismometer	40 kg
Horizontal seismometer	30 kg

The SKD-O seismometers, modified versions of the SKD equipped with a more powerful transducer with a ring magnet, are usually used in high-gain systems requiring an amplifier. The period of the SKD-O

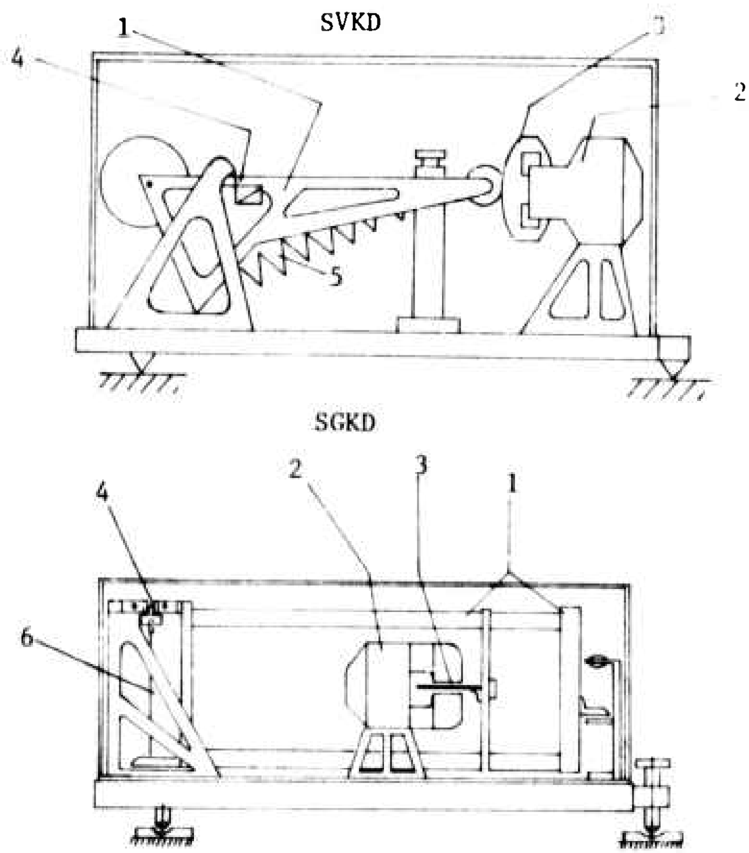


Fig. 30 -- Schematic drawing of the SVKD and SGKD seismometers [1]
1 - pendulum
2 - magnetic system
3 - coils
4 - flat spring
5 - zero-length spring
6 - suspension wire

is sometimes extended by means of an external capacitance. The SKD seismometers used in the long-period seismographs such as the SD-1 are modified by replacing the 25-ohm signal coil with a 900-ohm coil with a sensitivity of 20 V/(m/sec). Before 1970, the SKD and SKD-0 seismometers were used in most intermediate- and long-period seismographs, such as the standard broadband, extended-period SKD seismograph, the standard SD-1 long-period seismograph, and several others with galvanometric and visual recording then being developed.

2. DS [1]

The DS (Fig. 31) are recently developed, long-period seismometers with electromagnetic damping, intended primarily for galvanometric recording of the vertical and horizontal components of displacement generated by teleseismic events. Both the horizontal (DS-G) and the vertical (DS-V) seismometers are pendulum instruments equipped with a moving-magnet, stationary-coil transducer and a magnetic shunt that makes it possible to adjust the sensitivity of the signal and damping coils 10 to 15 percent. The natural period of the DS seismometers is adjustable between 5 and 30 sec. The DS-V is equipped with a zero-length spring.

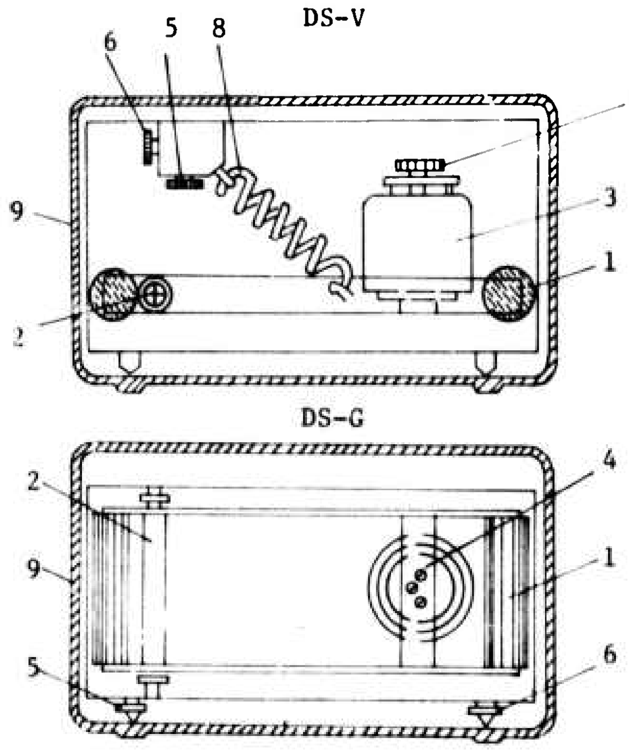


Fig. 31 -- Schematic drawing of the DS-V and DS-G seismometers [1]
1 - inertial mass
2 - axis of rotation
3 - moving magnet
4 - fixed coil
5 - pendulum-equilibrium-adjustment knob
6 - period-adjustment knob
7 - magnetic shunt
8 - zero-length spring
9 - seismometer housing

The DS seismometers have a remote pendulum-equilibrium-adjustment device and a remote period-adjustment control. They can also be used with electronic amplifiers coupled with visual or magnetic tape recorders. The DS are intended for operation at seismograph stations at temperatures between -10°C and +30°C and a relative humidity of up to 90 percent. The technical specifications of the DS seismometers are as follows:

Natural period	20 sec (nominal)
Reduced length	0.5 m
Signal coil sensitivity	400 V/(m/sec)
Damping coil sensitivity	20 V/(m/sec)
Calibration coil sensitivity ...	6 V/(m/sec)
Signal coil resistance	1000 ohms
Damping coil resistance	250 ohms
Calibration coil resistance	190 ohms
Moment of inertia	0.35 kg·m^2
Dimensions	85.8 x 36.6 x 42.2 cm
Weight	70 kg

3. Vertical Seismometer Used in the Long-Period Feedback Seismograph [56]

The electromagnetic moving-coil vertical seismometer used in the long-period, broadband, feedback seismograph described in Section II-C-13a is characterized by a more rational location of the mast, boom, and zero-length spring than is the SKD. Crossed flexure hinges are used to improve pendulum stability. The moment of inertia of the seismometer is greater than that of the SVKD, and it has a stiffer zero-length spring. The seismometer is equipped with signal and damping coils, two permanent magnets, a pendulum-equilibrium-position monitor, and a remote-centering device. A signal proportional to velocity fed back degeneratively to the transducer extends its natural period from 20 sec to 200 sec. One of the advantages of this seismometer is the increased stability at periods of 30 to 35 sec. The parameters of the seismometer are as follows:

Natural period	20 sec
Inertial mass	7.2 kg
Reduced length	0.44 m
Moment of inertia	0.7 $kg \cdot m^2$
Signal-coil sensitivity	266 V/(m/sec)
Signal-coil resistance	not given

4. SVD-III Vertical Seismometer [26]

The recently developed, experimental long-period SVD-III vertical seismometer is a pendulum instrument with electromagnetic damping and a moving-coil transducer. The seismometer is hermetically sealed and evacuated and is equipped with a remote pendulum-control and remote period adjustment devices. The magnetic system of the seismometer is shielded to eliminate eddy currents. Crossed flexure hinges have been replaced by two pairs of mutually perpendicular prismatic supports. The original design goal was a seismometer with a natural period of more than 100 sec. The technical specifications of the SVD-III are not available.

5. Feedback-Controlled Displacement Seismometer with Adjustable Parameters*

The long-period displacement seismometer with adjustable parameters, the most recent of Soviet long-period seismometers, is intended for use in the standard visual-recording and digital seismographs which are to be installed at Soviet base stations. It is a pendulum instrument equipped with an unspecified displacement transducer and a damping magnet-coil assembly. Part of the output of the signal transducer, fed back degeneratively through a low-pass filter, is proportional to displacement and makes the seismometer at least 50 times as stable as standard Soviet long-period models. Part of the output from the signal coil, fed back degeneratively to the damping magnet-coil assembly, is proportional to

---

*The material in this section is based on Z. I. Aranovich, D. P. Kirnos, and V. M. Fremd, *Apparatura i metodika seysmometricheskikh nablyudeniy v SSSR* (Instruments and Observation Methods Used at USSR Seismographic Stations), AN SSSR, *Institut fiziki Zemli*, Moscow, 1974, which was received just prior to the completion of this Report.

velocity of the pendulum and part to its acceleration. Varying the strength of the feedback signals proportional to acceleration and velocity by switching on different electronic modules makes it possible to vary the natural period, sensitivity, and damping of the seismometer through a wide range of values. The techincal specifications of the feedback-controlled seismometer are as follows:

Natural period	3 to 300 sec
Damping factor	0.5 to 10
Sensitivity	30 to 0.3 V/mm
Reduced length	~0.5 m
Moment of inertia	~2 $kg \cdot m^2$
Dynamic range	100 dB

C. SEISMOGRAPHS

1. SKD Broadband, Galvanometrically Recording Seismographs [1,28]

The SKD seismographs, the standard, intermediate-to-long period, broadband instruments with galvanometric registration, are intended to replace the SK intermediate-period seismographs. An SKD system consists of (1) an SVKD and two SGKD seismometers, (2) GK-VII galvanometers in which the alin alloy magnets are replaced by high-energy-content alnico magnets, thereby increasing the maximum magnetic field strength in the air gap of the magnet assembly, and (3) a PS-3M recording unit. The galvanometer is shunted with a resistance equal to that of the seismometer signal coil. The magnetic shunt can be used to adjust the damping factor of the galvanometer between 5 and 10 to 12. The nominal values of the instrumental constants of SKD seismographs are as follows:

$T_s = 25$ sec $\qquad \sigma^2 = 0.25$

$D_s = 0.5 \qquad \bar{v} = 1000$

$T_g = 1.2$ sec $\qquad v_{max} = \sim 1050$

$D_g = 8 \qquad T_m = 0.2$ to 20 sec

The magnification curve of a three-component SKD system with the values of instrumental constants given above is shown in Fig. 32.

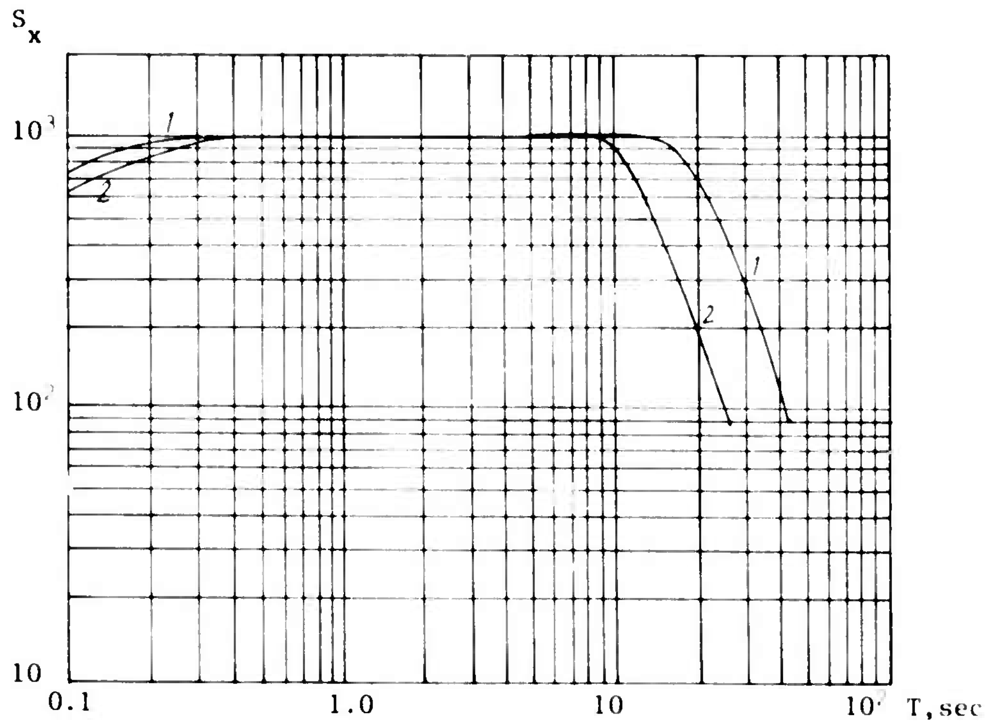


Fig. 32 -- Magnification curves of (1) a standard SKD seismograph with the values of the instrumental constants given above and (2) a standard SK seismograph [28]

2. SD-1 Galvanometrically Recording Seismographs [1,28]

The SD-1 seismographs are the standard, long-period, galvanometrically recording instruments, which were to be installed at all base and at certain regional stations. In 1970, however, SD-1 instruments were operating at only ten ESSN stations. The SD-1 system consists of an SVKD and two SGKD seismometers (modified by replacing the 10 to 25 ohm signal coils with 900 ohm coils), SPG-4a galvanometers, and a PS-3M recording unit. The nominal values of the instrumental constants of the SD-1 are as follows:

T_s = 25 sec	σ^2 = 0.20
D_s = 1	$\bar{v}$ = 900
T_g = 83 sec ±7 %	v_{max} = 1000
D_g = 0.5	T_m = 20 to 50 sec

Magnification curves of an SD-1 system with SPG-4a galvanometers are shown in Fig. 33.

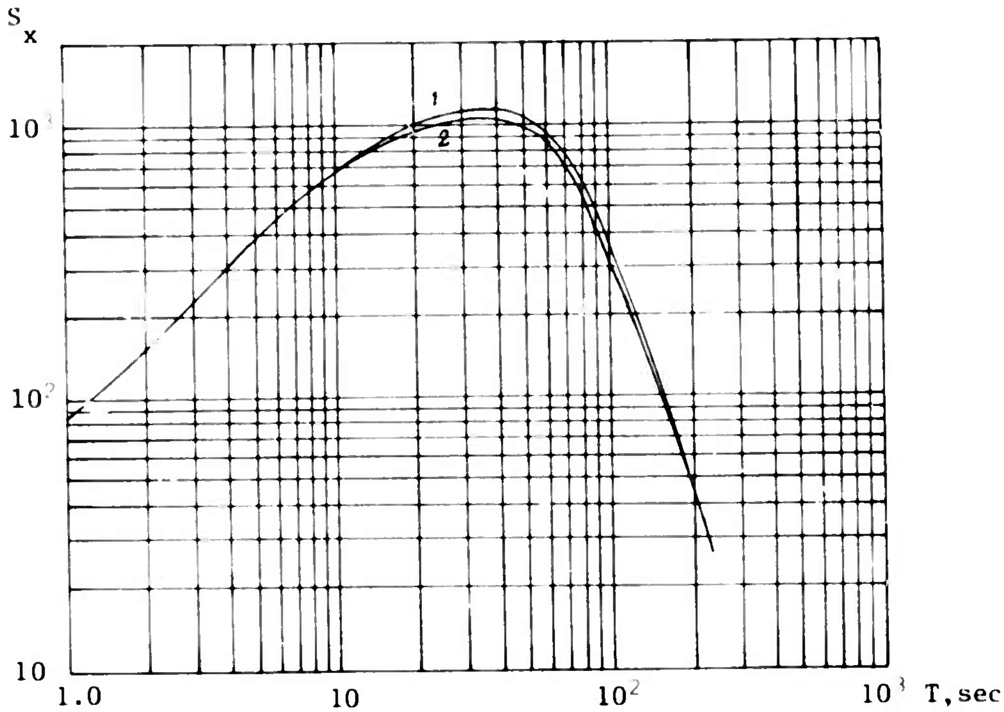


Fig. 33 -- Magnification curves of SD-1 seismographs with SPG-4a galvanometers [28] with the following values of instrumental constants:

	Curve 1 (N-S,Z)	Curve 2 (E-W)
T_s	25 sec	25 sec
D_s	1.0	1.0
T_g	82.2 sec	87 sec
D_g	0.50	0.50
σ^2	0.304	0.267
$\bar{v}$	970	940
v_{max}	1100	1020
T_m	20 to 60 sec	20 to 55 sec

Sometime in the early 1970s Soviet seismologists began to modify some of the SPG-4a galvanometers (T_g = 84 sec ± 7%) to SPG-4aM models ($T_s \approx$ 105 sec) in the SD-1 systems already in operation and in seismographs then being installed. The nominal values of the instrumental constants, and therefore the magnification curve of an SD-1 seismograph with a SPG-4aM galvanometer, is identical to that of a SD-2 instrument shown in Fig. 34 (curve 1).

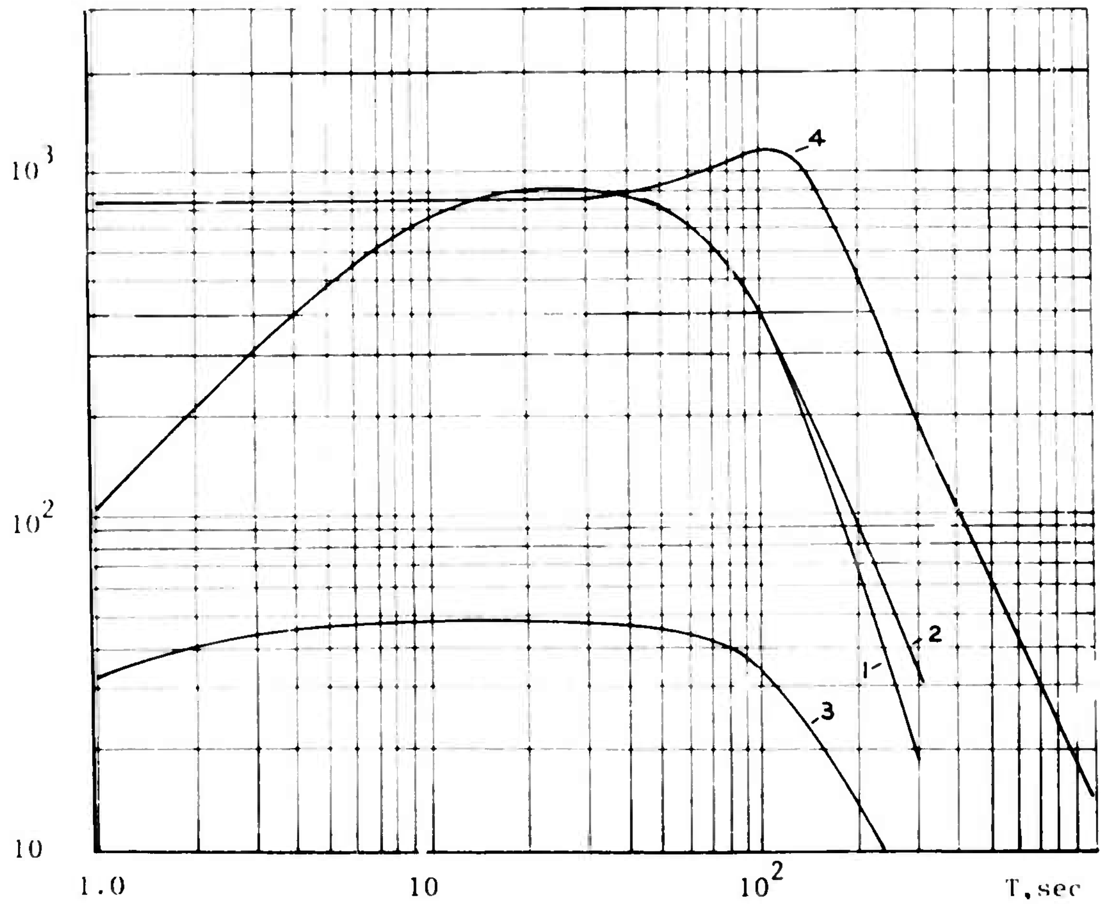


Fig. 34 -- Magnification curves of seismographs with the following instrumental constants operating at the Obninsk station in 1971 [58]:

	T_s (sec)	D_s	T_g (sec)	D_g	σ^2	v_{max}
SD-2 (curve 1)	25	1.3	104	0.7	0.24	940
Press-Ewing (curve 2)	30	1.62	94	0.82	0.012	880
KPCh-100 (curve 3)	20	10	108	0.7	7.2×10^{-3}	45
SDS-300 (curve 4)	(Instrumental constants are not available)					

3. SD-2 Galvanometrically Recording Seismographs [57]

The SD-2 long-period seismograph systems consist of one SVKD and two SGKD seismometers with a high-impedance coil (830 to 860 ohms) coupled to DG-100 galvanometers. Developed in the late 1960s they have been installed at the Obninsk and Simferopol' stations. The magnification curves of the SD-2 and the Press-Ewing seismographs operating at the Obninsk station in 1971 are shown in Fig. 34. The bandpass of the SD-2 is somewhat greater than that of the SD-1 and approaches that of the Press-Ewing seismograph.

4. KPCh-100 [58]

The KPCh-100 seismograph consists of an SVKD seismometer coupled to a DG-100 galvanometer. The magnification curve of a KPCh-100 seismograph is shown in Fig. 34.

5. SDS-200* Broadband, Galvanometrically Recording Seismograph [59]

The SDS-200 horizontal-component seismograph consists of a modified SGKD seismometer, a DG-200 galvanometer, and a PS-3M recording unit. The standard electromagnetic transducer in the SGKD seismometer was replaced by one with cylindrical coils and a more powerful magnet assembly with a cylindrical air gap. The signal, damping, and calibration coil sensitivities and resistances of the modified SGKD seismometer are as follows:

Coil	Coil Sensitivity [V/(m/sec)]	Coil Resistance (ohms)
Signal	122	1322
Damping	76	862
Calibration	2.64	97

*SDS-200 is the designation used in this Report for this seismograph, which is referred to in the Soviet literature only as a "broadband seismograph with constant gain in the period range between 2 and 200 seconds."

The moment of inertia of the modified SGKD seismometer is 0.3 kg·m^2 and its reduced length 0.5 m. The constants of the DG-200 galvanometer are close to the values shown in Table 6. The instrumental constants of the SDS-200 seismograph operating at three different gains are as follows:

T_s (sec)	D_s	T_g (sec)	D_g	σ^2	$\bar{v}$	v_{max}	T_m (sec)
19.7	10	197	0.5	0.23	120	160	150
19.7	6	197	0.5	0.38	200	275	150
19.7	5	197	0.5	0.46	240	330	130-140

The magnification curves of the SDS-200 seismograph calculated from the instrumental constants given above are shown in Fig. 35.

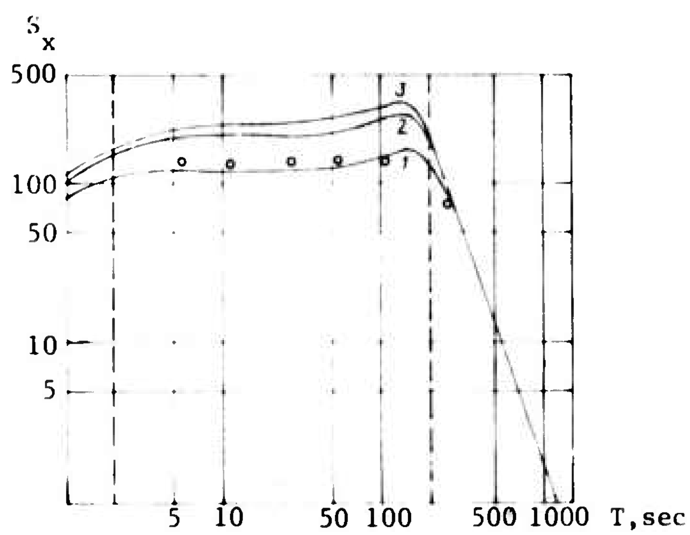


Fig. 35 -- Magnification curves of the SDS-200 seismograph calculated from the three sets of instrumental constants given above [59]. (o = experimental points on the magnification curve of the SDS-200 seismograph operating at the Obninsk station)

6. SDS-300 Broadband, Galvanometrically Recording Seismograph

The SDS-300 consists of a modified, SVKD seismometer described in Section II-B-1 and a 300 sec DG-300 galvanometer (see Table 6). A magnification curve of the SDS-300 seismograph is shown in Fig. 34. The instrumental constants of the SDS-300 are unavailable.

7. Standard, Broadband, Visual-Record Seismograph System [1]

The magnification curve of seismographs recommended by the Institute of Physics of the Earth for use in standard, long-period, broadband, visual-recording systems to be deployed at Soviet seismographic stations is shown in Fig. 36 (curve 1). The system consists of a DS or a SKD seismometer with T_s = 20 sec and D_s = 0.5; an IPR-M parametric, variable reluctance amplifier system with T_g = 2 to 4 sec and D_g = 10; and a SPR hot-pen recorder. The maximum gain that can be achieved with DS seismometers is 500, while the maximum magnification obtained with SKD is only 50. The UPN-3M amplifier can be substituted for IPR-M, and N-002 or PST hot-pen recorders can be used instead of the SPR.

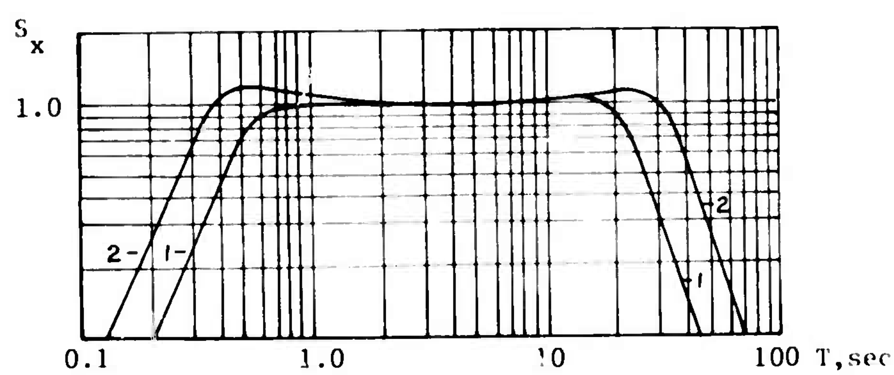


Fig. 36 -- Magnification curves of standard broadband visual-recording seismograph systems [1]
Curve 1 - seismometers without external capacitors
Curve 2 - seismometers with external capacitors

8. Standard, Broadband, Visual-Recording Seismograph System with Extended Frequency Response [1]

The magnification curve of standard long-period, broadband, visual-recording seismograph systems with an extended frequency response is shown in Fig. 36 (curve 2). The system, which is to be deployed at Soviet seismographic stations, consists of a DS seismometer with T_s = 20 sec (extended to 30 sec by means of an external capacitor connected to the signal coil) and D_s = 1.0 to 0.7; an IPR-M parametric variable reluctance amplifier system with T_g = 2 to 4 sec and D_g = 15; and a SPR, N-002, or PST hot-pen recorder. The maximum gain of the system is about 100.

9. SMD Broadband, Galvanometrically Recording Seismograph [60]

A long-period displacement seismograph consisting of a modified Ostrovskiy tiltmeter was tested and installed at the Obninsk station sometime in the late 1960s. The tiltmeter, which responds to accelerations at periods exceeding T_s = 5 to 10 sec, was modified (1) by incorporating an RC filter into the negative-feedback loop of the electromagnetic transducer, which is used for pendulum centering, and (2) by overdamping the M17/13 (T_g = 20 sec, D_g = 13) galvanometer. A high-pass RC filter with a fall off of 12 dB/octave at T $\approx$ 1800 sec is used to suppress tidal wave signals. Other changes included replacement of the transducer coil with one having a much larger generator constant. The SMD seismometer operates at a gain of 200, and its magnification curve, shown in Fig. 37, is flat between one and 600 sec.

10. SGK Hall Effect, Visual-Recording Seismograph [61]

A long-period, horizontal-component, ink-pen displacement seismograph was developed by adding a Hall-effect pickup to an otherwise unmodified transducer of the standard SGK broadband, intermediate-period seismograph. The seismometer, with a Hall-effect pickup attached to the end of the boom, responds to displacements rather than velocities. A block diagram of the Hall-effect seismograph is shown in Fig. 38. The damping coil (C_2) in the transducer remains unchanged, while the

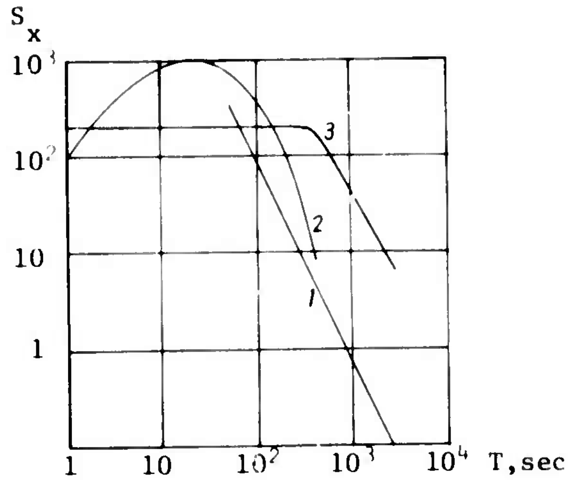


Fig. 37 -- Magnification curves of
1 - Ostrovskiy tiltmeter
2 - Press-Ewing seismograph
3 - SMD seismograph [60]

signal coil (C_1) is now used for calibration and for remote pendulum-equilibrium adjustment (performed by means of a microammeter in the load circuit of the F117/3 galvanometer phototube amplifier, connected to the Hall-effect pickup through resistance R_1). Rigid suspension of the galvanometer (T_g = 1.34 sec) in the phototube amplifier eliminates the need for feedback. The signal is fed into a low-pass filter, which suppresses 5 to 7 sec microseisms and serves as an integrating circuit to provide sufficient gain at longer periods, and into a transistorized F122 dc amplifier, modified so as to increase its gain. An isolating capacitor between the filter and the dc amplifier decreases sensitivity to tilting due to earth tides. The seismometer is covered with a plastic foam cover. Figure 39 shows the frequency response curves of the Hall-effect seismometer, low-pass filter, and Hall-effect seismograph. The maximum gain of the seismograph is 10^4 at T = 33 sec.

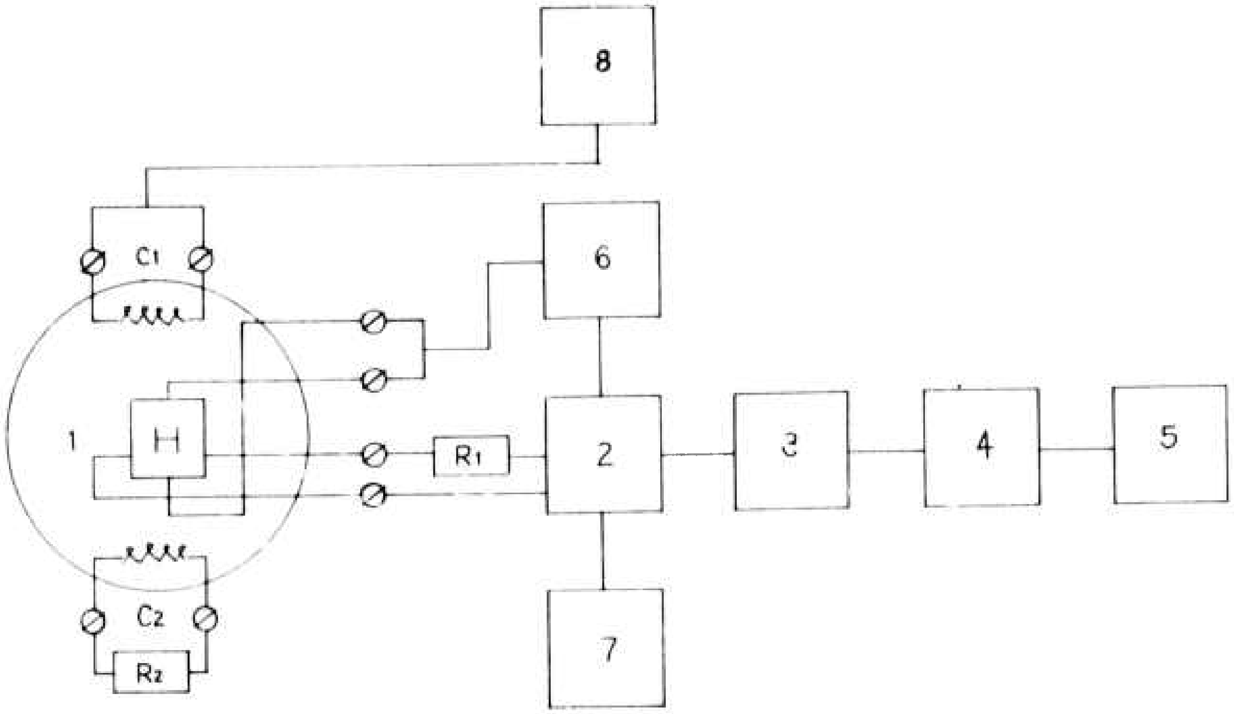


Fig. 38 -- Block diagram of the Hall-effect seismograph [61]

1 - transducer
H - Hall-effect pick-up
C_1 - damping coil
C_2 - calibration coil
R_1 - gain control resistor
2 - F117/3 galvanometer-phototube amplifier
3 - low-pass filter
4 - dc amplifier
5 - N-322 or a PVZ-T ink-pen recording unit
6 - Hall-effect pick-up power supply
7 - phototube amplifier power supply
8 - calibration signal generator

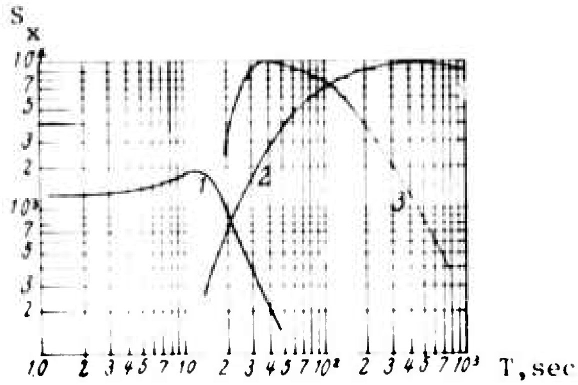


Fig. 39 -- Frequency-response curves of
1 - Hall-effect seismometer
2 - low-pass filter
3 - Hall-effect seismograph [61]

11. SGKD-O Hall-Effect High-Gain Seismograph System [62]

The SGKD-O Hall-effect, high-gain, long-period seismograph system (v_{max} = 20,000 at T = 50 sec) consists of two 25-sec seismometers, (one visual, one photographic), two FM tape recorders, and associated electronic components developed by KSE in the mid-1960s. It is intended for registration of seismic signals in the 0.01 to 15 Hz passband at two gains separated by ~46 dB. The sensitivity of SGKD-O seismometers was increased by incorporating Hall-effect pickups in their transducers -- in a way similar to that just described in Section II-C-11. The electronic components of the seismograph system include a low-noise preamplifier, a modulator with a blocking oscillator which generates the 250 Hz carrier, an amplifier, two pulse-shaping circuits, a frequency converter (250 Hz ± 50% to 125 Hz ± 50%) to reduce crosstalk, and impedance matching circuits. The signals are recorded by an eight channel (six signal, one timing, one wow-and-flutter compensation) operational tape unit recording continuously on 19-mm tape at a speed of 1 cm/sec. The amplifier of one of the signal channels is also connected to a demodulator and to a trigger which above a certain threshold activates, for a specified period of time, the read-head of the storage recording system. The FM signals from the read-head are amplified, shaped, and recorded with signal compression by an eight-channel storage tape recorder and, at the same time, demodulated and registered by a photographic and visual-recording unit. A one-minute delay loop between the write-head of the operational tape recorder and the read-head of the storage recording system makes it possible to register seismic events large enough to trigger the storage tape recorder without a loss of first motion. Since vertical SVKD-O Hall-effect seismometers were apparently not developed, only four of the six signal channels of the operational and storage tape recorders were being used. The technical specifications of the recording units are as follows:

Frequency range	0.01 to 15 Hz	
Modulation type	FM	
Center frequency and percent modulation		
generated	250 Hz ± 50%	
recorded	125 Hz ± 50%	
Operating cycle	Continuous recording on operational tape recorder. Triggered recording of selected events on storage tape recorder, with automatic reset, and on a photographic and a visual recorder.	
Heads	8 tracks 3 high gain, 3 low gain 1 timing, 1 wow-and-flutter compensation	
Tape	Operational tape recorder	Storage tape recorder
width	19 mm	19 mm
speed	10 mm/sec	--
expenditure	<1 km/day	varying
Dynamic range		
one channel	57 dB	
two channels	100 dB	
Timing	62.5 and 187.5 Hz signals provide minute and hour marks from a quartz clock	
Tape speed compensation frequency	350 Hz	

12. Gyroseismometer [63]

A recent addition to Soviet long-period instruments is a negative-feedback gyroseismometer consisting of a standard SK horizontal seismometer, with $T_s = 10$ sec and $D_s = 0.7$, and incorporating a single-degree-of-freedom gyroscope,* with an angular momentum of 20,000 gm·cm·sec, in an elastic suspension. The natural period of the gyroseismometer is increased by a negative feedback signal proportional to the second derivative of the angle of rotation (angular acceleration) of the pendulum. The natural periods of the gyroseismometer are 0.06 sec (17 Hz) and 740 sec. The angular magnification (n/θ) at 100 sec and 740 sec is 44 and 6, respectively. The output voltage of the parmetric transducer is proportional to the angle of rotation of the gyroscope relative to the pendulum. The gyroseismometer is damped by feeding part of the signal from the parametric transducer to the damping coil of the electromagnetic transducer of the pendulum. The gyroseismometer, connected to an N-39 pen recorder, can register displacement, velocity, or acceleration.

13. Long-Period Velocity and Displacement Feedback Seismographs**

Soviet seismologists have described three different types of feedback seismographs. The first, the earliest and simplest, consists of an electromagnetic, moving-coil seismometer. In this model part of the signal, initially proportional to velocity, is differentiated by an RC circuit in the feedback loop so that the signal, now proportional to acceleration, is fed back degeneratively to the signal coil.

---

*Although no details are given on how the gyroscope is incorporated in the seismometer, the method appears to be similar to that described by Y. T. Huang in the *Bulletin of the Seismological Society of America*, Vol. 53, No. 4, 1963, pp. 821-823.

**Except for the material in Part 13a, all of this Section is based on data taken from: (1) Z. I. Aranovich, D. P. Kirnos, and V. M. Fremd, *Apparatura i metodika seysmometricheskikh nablyudeniy v SSSR* (Instruments and Observation Methods Used at USSR Seismographic Stations), AN SSSR, Institut fiziki Zemli, Moscow, 1974, which was received just prior to the completion of this Report; and (2) A. V. Rykov, "Increasing Seismometer Stability by Means of Feedback Near the Boundary of Its Stability," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 26-32.

The second type, a feedback-controlled velocity seismograph, includes an electromagnetic-signal transducer and a damping-coil transducer mounted on the pendulum of the seismometer. The seismograph utilizes degenerative feedback signals, proportional to the pendulum's velocity and acceleration, fed back to the damping-coil transducer.

The third type, a feedback-controlled displacement seismograph, includes an unspecified displacement-signal transducer and a damping-coil transducer mounted on the pendulum of the seismometer. It utilizes degenerative feedback signals, proportional to the pendulum's velocity, acceleration, and angular displacement from its center position, fed back to the damping-coil transducer.

While the general review of basic principles of degenerative feedback presented below applies specifically to the third type (the feedback-controlled displacement seismograph), the discussion of negative feedback proportional to acceleration and velocity and to velocity alone also applies to the other two types of Soviet feedback seismographs.

The feedback features of the feedback-controlled displacement seismograph are most conveniently discussed in terms of the feedback-loop constants k_d, k_v, and k_a, where the subscript indicates that the feedback is proportional to the angular displacement of the pendulum from its center position d, its velocity v, and acceleration a.

In general, a signal from the displacement transducer fed back degeneratively to the damping coil through a low-pass RC filter with a long time-constant increases the seismometer's stability and the linearity of its response. The increase in stability of such a seismometer is determined by the centering factor (equal to the loop constant k_d) which is given by the following equation:

$$k_d = \frac{\theta_o - \theta_k}{\theta_k} \qquad (1)$$

where θ_o and θ_k are the pendulum's initial displacement from its center position without and with displacement feedback, where the pendulum motion is generated by a constant acceleration or tilt.

A signal proportional to the pendulum's acceleration, fed back degeneratively to the damping-coil transducer increases the seismometer's moment of inertia K_s to a new value K_{s_f} which can be determined from the following equation:

$$K_{s_f} = K_s(1 + k_a) \tag{2}$$

The principal result of the increase in K_s is the increase in the natural period of the seismometer to a new value T_{s_f} given by the following equation:

$$T_{s_f} = T_s(1 + k_a)^{1/2} \tag{3}$$

In theory, the natural period of a seismometer can be increased indefinitely by increasing the pendulum's moment of inertia; this is done without deterioration of the seismometer's stability, which is much improved by negative displacement feedback. In practice, the increase in the natural period is limited by the decrease in damping, which is inversely proportional to the period increase, and by an even more rapid decrease in sensitivity. The decrease in damping and sensitivity due to degenerative acceleration feedback is given by the following equations:

$$D_{s_f} = D_s(1 + k_a)^{-1/2} \tag{4}$$

$$S_{s_f} = S_s(1 + k_a)^{-1} \tag{5}$$

where the subscript s_f identifies the seismometer constant under consideration in the presence of feedback and subscript s refers to the constant in the absence of feedback.

When the natural period of a seismometer with negative feedback proportional to acceleration is extended to the point that sufficient damping cannot be achieved by means of electromagnetic damping alone, additional damping can be introduced using feedback proportional to the pendulum's velocity. Such a signal, fed back degeneratively to the damping coil, increases the seismometer's damping in accordance with the equation:

$$D_{s_f} = D_s(1 + k_v) \qquad (6)$$

This increase in D_s is more than sufficient to offset the drop in damping due to feedback proportional to acceleration. Thus, the increase in the natural period of a seismometer with degenerative feedback signals proportional to both velocity and acceleration is limited primarily by the decrease in its sensitivity (see Eq. (5)). The signal strength of the two types of feedback signals can be controlled by means of electric circuits in the feedback loop which make it possible to vary the natural period and damping of the feedback-controlled seismometer.

a. Broadband, Negative-Feedback, Vertical-Component Velocity Seismograph [56]. An experimental model of a broadband, negative-feedback, vertical-component velocity seismograph, operating at one-fourth of its maximum gain of 2000, was installed at the Obninsk station in early 1970. The signal generated by the electromagnetic, moving-coil seismometer described in Section II-B-3 is amplified by an IPR galvanometer amplifier with a voltage gain of $2 \cdot 10^6$, input noise of less than 0.002 μV, output voltage of ±10 V, output impedance exceeding 500 ohms, and galvanometer natural period T_g = 3 sec.

Part of the signal from the IPR amplifier is fed back to the seismometer damping coil through an RC differentiating circuit forming the feedback loop. The effect of the feedback, which is proportional to acceleration, is to increase the natural period of the seismometer. The new natural period can be determined approximately from Eq. (3), where k_a, the loop constant for feedback proportional to acceleration, is given by the following formula:

$$k_a = gS_x^2 l^2 C/K_s \qquad (7)$$

where g is the feedback loop gain, $S_{\dot{x}}$ is the velocity sensitivity of the seismometer, l its reduced length, and C the capacitance of the feedback loop. Formula (7) becomes exact when $RC\omega_f << 1$, where R is the resistance of the feedback loop and ω_f is the angular corner frequency of the low-pass filter. For the seismograph under consideration, RC = 0.04 sec, $\omega_f/2\Pi = 1$ Hz, and formula (7) is sufficiently accurate. The values of g, $S_{\dot{x}}$, l, and C at a given value of K_s were selected so that $T = 10\ T_s$. Since $T_s = 20$ sec, the new seismometer period with a negative feedback proportional to acceleration is T = 200 sec.

The other part of the signal output is fed into high-pass and low-pass filters, amplified by a transistorized parametric dc amplifier and recorded by a heated-stylus recorder.

The high-pass filter, with a time-constant of ~200 sec, serves to eliminate long-period noise due to pendulum and amplifier drift (as much as 3 to 5 μm per day, which would otherwise cause seismograms to display departure from zero of up to 10 mm every 24 hours). A low-pass filter with a time constant of ~5 sec is used to shape the high-frequency part of the response curve.

The principal parameters of the transistorized, parametric dc amplifier are as follows:

Voltage gain	10^3
Input noise	<1 μV
Input impedance	10 kohms
Thermal drift at the input	$<10^{-5}$ V/°C
Output voltage	±10 V
Output impedance	<500 ohms
Power supply	12 V, 0.05 amp

A single-channel SPR heated-stylus recorder (see Section I-D-3-d), operated at a speed of 6 mm/sec, is used for registration of seismic signals.

b. Feedback-Controlled Velocity Seismograph with Adjustable Seismometer Constants. A schematic drawing of a feedback-controlled velocity seismograph is shown in Fig. 40a. A voltage proportional to the velocity of the pendulum (1) is generated by the signal coil of an electromagnetic transducer (2) of a pendulum seismometer. This signal is amplified by a dc amplifier (3) and fed to a digital- or visual-recorder.

Part of the output signal is fed degeneratively across capacitance C of the feedback loop and to the coil of the damping-coil transducer. Since the feedback time-constant RC is sufficiently small so that $2\Pi RC/T << 1$, the feedback signal is differentiated by the RC circuit. This part of the feedback signal is proportional to acceleration and thus increases the seismometer's natural period in accordance with Eq. (3) with the loop constant given by formula (7), which applies if one disregards the potentiometer. However, the degenerative acceleration feedback also decreases the damping and sensitivity of the seismometer in accordance with Eqs. (4) and (5).

Another part of the signal is fed degeneratively across resistance R_1 and to the coil of the damping coil-transducer (4). This signal remains proportional to the velocity of the pendulum and thus increases the seismometer's damping in accordance with Eq. (6). The natural period and damping of the seismometer can be controlled by means of a potentiometer P and resistance R_1, respectively.

c. Feedback-Controlled Displacement Seismograph with Adjustable Seismometer Constants. A schematic drawing of a feedback-controlled displacement seismograph is shown in Fig. 40b. It differs from the feedback-controlled velocity seismograph described in Section II-B-13-b in that (1) the signal is generated by an unspecified displacement transducer of the pendulum seismometer described in Section II-B-5 rather than an electromagnetic transducer, and (2) it has different feedback-loop circuitry. Improved stability is achieved by means of a signal fed back degeneratively through an R_1C_1 filter of an $R_1C_1R_1$ circuit. Negative feedback proportional to acceleration to increase the seismometer's natural period is obtained by means of two differentiating RC circuits. The increase in the natural period and the

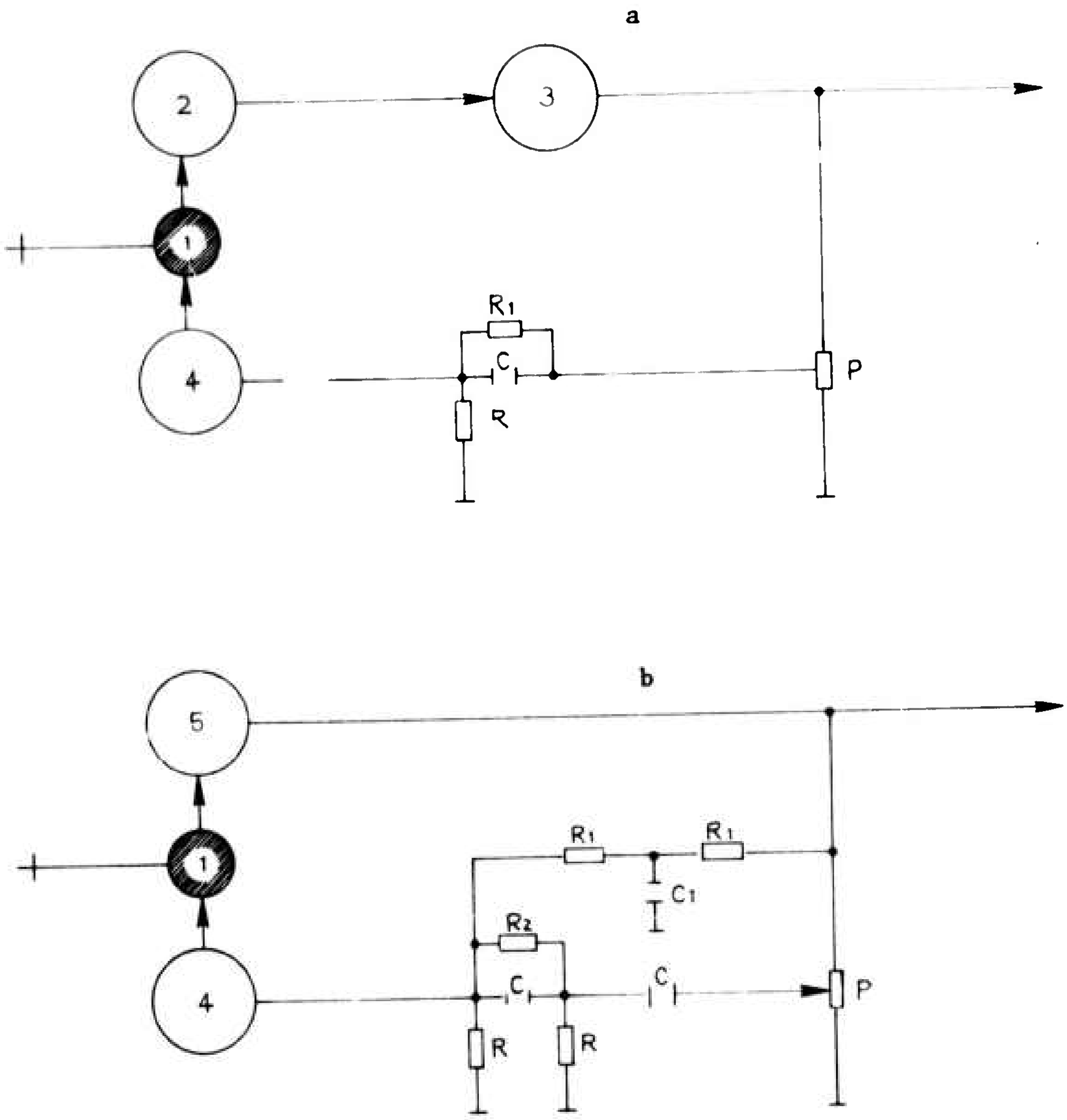


Fig. 40 -- Schematic drawing of feedback-controlled seismographs with adjustable seismometer constants -- (a) velocity seismograph; (b) displ .cement seismograph
1 - pendulum
2 - electromagnetic signal transducer
3 - dc amplifier
4 - electromagnetic-damping transducer
5 - unspecified signal-displacement transducer

decrease in the damping factor and sensitivity of the seismometer due to feedback proportional to acceleration are given by Eqs. (3) through (6) with the value of the loop constant given by the following equation:

$$k_a = S_{\dot{x}} l \beta RC^2 / K_s \quad (8)$$

The increase in damping is achieved by means of a signal from the displacement transducer fed back degeneratively across an RC circuit, and differentiated by it, so that the feedback is proportional to velocity.

In the model under consideration, the natural period of the seismometer at a constant feedback loop gain can be varied between 3 sec and 300 sec by varying the strength of the feedback signal proportional to acceleration by means of a potentiometer (P). The damping factor at constant feedback-loop gain can be varied between 0.5 and 10 of its critical value by means of resistance R_2. In practice, the feedback signal and seismometer constant are varied by switching on different electronic modules.

III. SPECIAL SEISMOGRAPH STATION NETWORKS

A. THE KOD DIGITAL SEISMOGRAPH STATION NETWORKS

The KOD seismograph station networks for detection and identification of nuclear explosions consist of three to five stations equipped with three-component KOD digital seismograph systems. Selection of interesting events from seismic data acquired by stations in the network is performed at a central editing facility [64,65]. Preliminary processing of these selected events, including frequency filtering, crosscorrelation, and smoothing, is performed by a system deploying a special-purpose computer. Further processing and analysis of significant events is done on a general-purpose computer using digital tapes from several KOD systems [64,65,66]. It is claimed that several KOD networks have been operating at unspecified locations in several regions of the Soviet Union since 1966 [65,67,68].

1. KOD Digital Seismograph System

The KOD seismograph system (see block diagram in Fig. 41) consists of a three-component set of moving-coil SKD long-period seismometers (T_s = 30 sec, D_s = 0.45, S_x = 60 μV/μm at 1 Hz, increasing with frequency at 6 dB/octave) and a three-component set of SKM-3 short-period seismometers (T_s = 3.5 sec; D_s = 0.45, S_x = 2000 μV/μm at 1 Hz also increasing with frequency at 6 dB/octave). The signals from each seismometer are fed into a two-stage, negative-feedback preamplifier system. The preamplifier coupled with SKD seismometers consists of two F117/5 galvanometer phototube amplifiers, coupled with SKM-3, or two F117/3s. (For convenience, the preamplifiers used with each SKD and the same component SKM-3 seismometer are packaged together as a single unit, sometimes called the DFU amplifier.) The parameters of the feedback loop of each preamplifier are adjusted for a gain of 10^3 at T = 33 sec [65].

The principal characteristics of the preamplifier used with SKM-3 seismometers are as follows [1]:

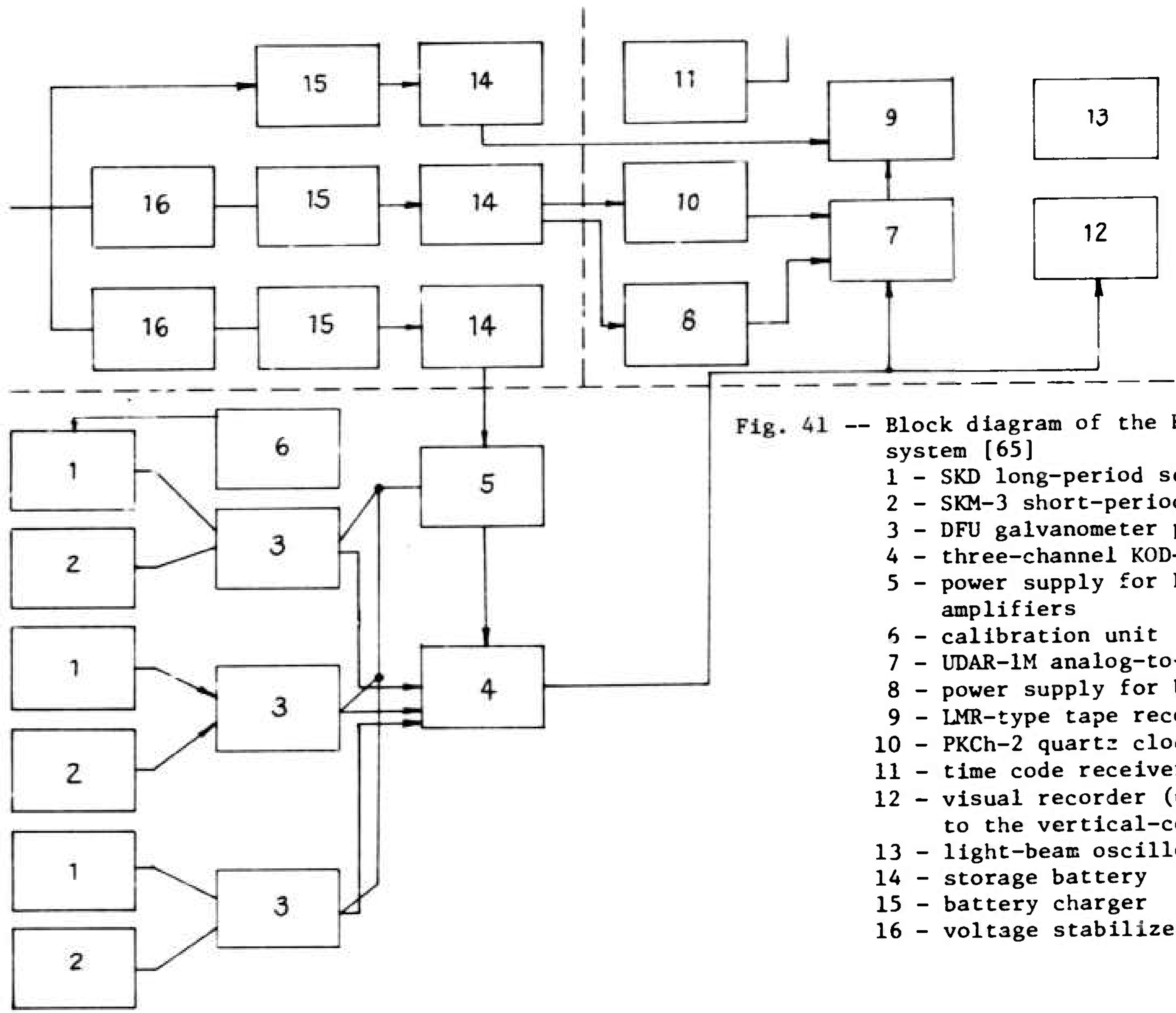


Fig. 41 -- Block diagram of the KOD seismograph system [65]

1 - SKD long-period seismometer
2 - SKM-3 short-period seismometer
3 - DFU galvanometer phototube amplifier
4 - three-channel KOD-I amplifier system
5 - power supply for DFU and KOD-I amplifiers
6 - calibration unit
7 - UDAR-1M analog-to-digital converter
8 - power supply for UDAR-1M converter
9 - LMR-type tape recorder
10 - PKCh-2 quartz clock
11 - time code receiver
12 - visual recorder (usually connected to the vertical-component channel)
13 - light-beam oscillograph
14 - storage battery
15 - battery charger
16 - voltage stabilizer

Period range	0.1 to 100 sec
Gain	0.5 to 2 x 10^5
Input noise (peak-to-peak)	0.1 μV
Dynamic range	60 dB
High-frequency roll off	24 dB/octave

The outputs of the DFU amplifier are summed at the input of a transistorized, three-channel KOD-I amplifier system consisting of (1) a postamplifier, (2) a low-pass RC filter,* with a drop of 40 dB at 50 Hz, and a RC notch filter (adjustable between 0.140 and 0.148 Hz) with an attenuation rate of 32 dB/octave, and a drop of 40 dB at the notch, intended to suppress 5 to 8 sec microseisms. The KOD-I, intended for operation in the period range T = 0.3 to 33 sec, has two outputs per channel with a gain of 10 and 100. However, excluding the sawtooth control voltage, only four data channels can be recorded on magnetic tape, with the usual combination being three-components high gain and a vertical-component low-gain, or vice versa [65].

Signals from the KOD-I are sampled sequentially by a scanner of the UDAR-1M analog-to-digital converter, at a rate of 33 samples per second. The analog-to-digital converter is a 10-channel (only 5 are used), 11-bit successive approximation unit with a dynamic range of ±5 V and with the least significant bit thus representing ~ ±5 mV. The 5 data channels are recorded in parallel in 11-bit code on the 17-track 35-mm magnetic tape of a LMR-type recorder. The 12th bit on the tape is a parity check. The absolute time, converted by a separate unit into a 12-bit code, is recorded at 30-sec intervals, resulting in the loss of a data point from each of the 5 channels every 1000 conversions. The 13th bit, placed once every 5 samples, identifies the first channel. The 13th through the 17th tracks identify all 5 channels once every 500 samples. The packing density is 10 bits/mm at a tape speed of 15.5 mm/sec. A quartz clock, synchronized by radio once every 12 hours, maintains an overall accuracy of 0.1 sec per day [65].

---

*Probably a separate unit.

All channels are calibrated by feeding 10-V step-function-current pulses of 28-msec duration into the damping coils of the seismometers. The transfer functions of all channels are recorded on each tape and are used by the computer to calculate the frequency-response curves of the channels. Transfer functions registered by visual recorders are also compared with standard functions [69].

The response curve of a high-gain channel of the KOD system operating at maximum gain, computed from the constants of the system, is shown in Fig. 42. The maximum displacement sensitivity of this system at 1 Hz is 6.5 V/μm, and the ratio of maximum gain at high frequencies to that at low frequencies is 25. The low frequency roll off is 30 dB/octave and the high-frequency roll off is 12 to 18 dB/octave. The attenuation rate of the response curve on the left and right sides of the notch at 0.145 Hz are 28 dB/octave and 40 dB/octave, respectively. At low frequencies (f = 0.4 to 3.5 Hz) the KOD system, operating at maximum gain and the vertical-component channel recording at two different magnifications can record displacements between 3 nm and 12 μm; at longer periods (T = 14 to 40 sec) the range of recordable displacements drops to 0.08 to 300 μm [65].

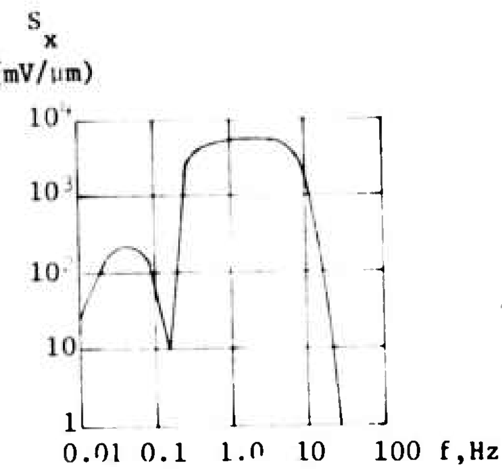


Fig. 42 -- Displacement sensitivity curve of a high-gain channel of the KOD system operating at a maximum gain, determined from the constants of the system [65]

An experimental response curve of one of the channels of the KOD system operating below maximum gain and the same curve calculated on a computer from the transfer function for the system are shown in Fig. 43 [69]. Figure 44 shows the response of the low-gain channel of the KOD system operating at maximum gain for registration of teleseismic events. The maximum sensitivity of the low-gain channel of the KOD system is 2 V/μm at 1 Hz and 50 mV/μm at 0.1 Hz. The two levels on the response curve, one with a sensitivity about 40 times that of the other, are needed to record both S and P phases with the same number of binary digits (to the same least significant bit), even though the amplitude of P exceeds that of S up to 40 times [68].

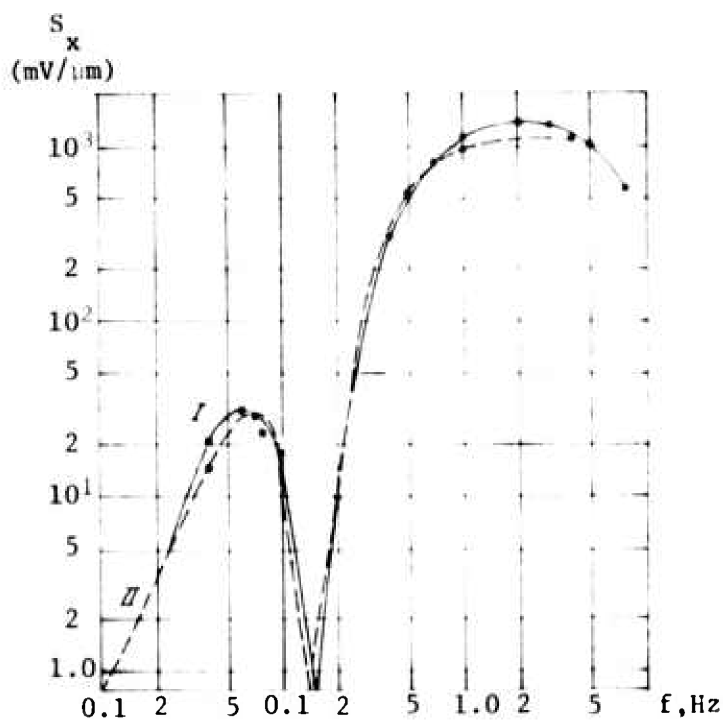


Fig. 43 -- Displacement sensitivity curves of the KOD system operating below maximum gain [69]
I - derived experimentally
II - computed from the transfer function

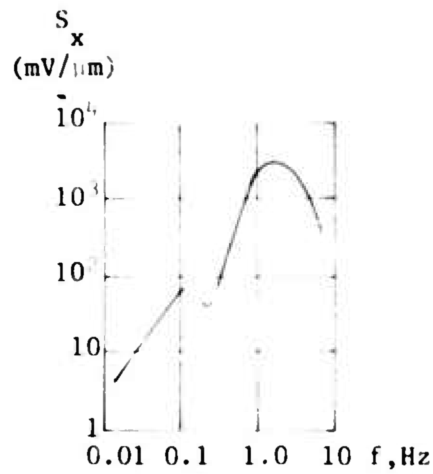


Fig. 44 -- Displacement sensitivity curve of a low-gain channel of the KOD system operating at maximum gain [68]

2. Editing and Preliminary Processing Systems

The magnetic tapes and seismograms from several KOD stations are unloaded three times a day and sent to a central editing facility. Interesting events observed on the seismograms from a visual recorder, acquired at the same time as the magnetic tapes, are manually selected and transcribed onto another tape. During transcription, this tape is decoded on a digital-to-analog converter and rerecorded on photographic paper [65].

Preliminary processing of interesting events is performed by a system that includes a special-purpose computer developed specifically for that purpose. A block diagram of the preliminary processing system is shown in Fig. 45.

The specifications of the special-purpose computer are as follows [66,67]:

Type	second generation, fixed point
Operating speed	83,100 adds/sec; 37,700 mults/sec
Memory type	core memory
Memory capacity	192 11-bit words
Access time	12 μsec

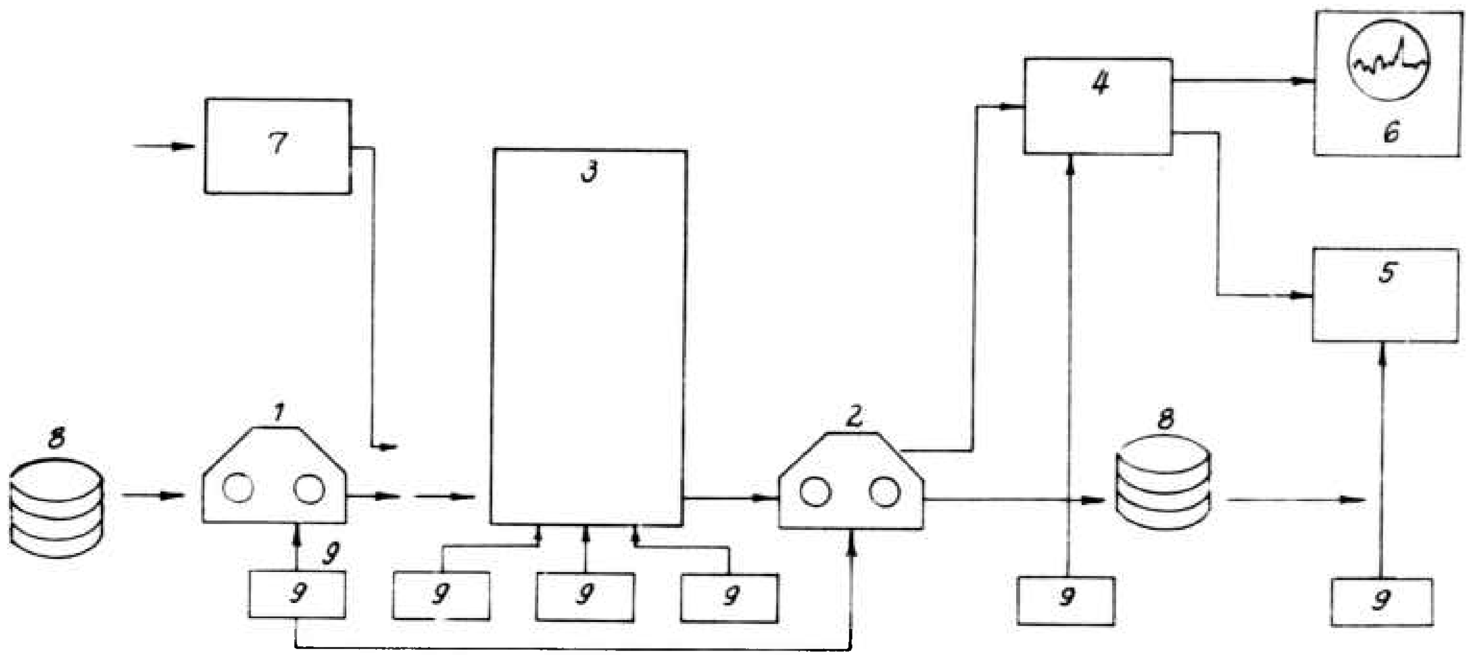


Fig. 45 -- Block diagram of the preliminary processing system [67]

1 - tape drive (input)
2 - tape drive (output)
3 - special-purpose computer
4 - digital-to-analog converter
5 - N-700 light-beam oscillograph
6 - oscilloscope
7 - UDAR-1M analog-to-digital converter (may be connected if needed)
8 - magnetic tapes
9 - power supply

Output precision .... 3 decimal places

I/O transfer rate per tape channel .... 3 msec

Dimensions .... two cabinets, each 30 x 110 x 175 cm

The preliminary processing system is capable of performing the following operations on seismic data recorded in digital form on magnetic tape by each of the five channels of the KOD digital seismograph system [66,67]:

1. Frequency filtering in accordance with the following formula:

$$Y(t_i) = k\sum_{j=0}^{n} f(t_{i-j})\cdot h_j \tag{9}$$

where $f(t_{i-j})$ is the signal, h_j is the impulse response of the filter, $n + 1$ is the number of data points, and k is the scale factor. For $n = 64$ an attenuation rate of 40 to 50 dB/octave can be achieved. The time required for one calculation using formula (9) with $n = 1$ is 390 μsec. Thus, for $n = 64$ the required computer time is 24 msec.

2. Crosscorrelation in accordance with a formula analogous to (9), except that h_j represents a function with which crosscorrelation is to be carried out. In particular, crosscorrelation includes extraction of late arrivals.

3. Smoothing in accordance with the following formula:

$$Z(t_i) = k\sum_{j=0}^{n} Y(t_{i-j}) \tag{10}$$

4. Determination of the mean intensity in accordance with the formula:

$$I(t_i) = k\sum_{j=0}^{n} |Y(t_{i-j})| \tag{11}$$

The following operations are performed on the data: (1) the preliminary processing system selects one of the channels on the magnetic tape of selected events; (2) the time code is read in without any change; (3) the excess data are decimated by a factor of 2^m, where m can be set between 0 and 6; (4) the offset binary code used initially is converted to a signed binary code with the zero-volt level taken to be the mean value of the range of measurements; (5) the output of the preliminary processing system is recorded on magnetic tape, in the same binary code as the original input, for possible further processing on a general-purpose computer [67].

According to [67], the operating capability of the special-purpose computer was to be improved by

1. Doubling the main memory capacity by adding a second core and thus increasing the number of values of the impulse response stored in the memory to n = 128.
2. Quadrupling the operating speed of the computer by computer hardware manipulation.
3. Adding the capability for multichannel processing.

Furthermore, the preliminary processing system could also be converted to a rather sophisticated triggering unit for the KOD system operating in standby mode [66].

B. THE TRIANGLE NETWORK

The Triangle network consists of three seismographic stations -- Talgar (43°14'N, 77°14'E) in the Kazakh SSR, and Frunze (42°50'N, 74°37'E) and Naryn (41°26'N, 76°00'E) in the Kirgiz SSR -- that form a roughly equilateral triangle with sides 200 km long. The network, which became operational in 1968, is equipped with identical three-component digital seismograph systems that record in the frequency range 0.003 to 5 Hz. The magnetic tapes from the three stations are unloaded and sent by truck to a central editing facility. Interesting events observed on seismograms from a visual recorder, which are obtained simultaneously with the magnetic tapes, are manually selected, transcribed onto another tape, and sent to the computer-processing facility. The digital seismograph system used in the processing systems of the Triangle network is similar to that of the KOD system shown in Fig. 41.

1. Seismograph Systems at the Triangle Network

The seismic instruments of the array consist of three digital seismographs which record the three components of motion at normal gain (the vertical-component channel, however, has a double output -- normal and one-tenth of normal, or low gain) and a vertical-component, high-gain digital seismograph. The basic difference between the high-gain and the three-component seismographs are the seismometers and an extra postamplifier used with the high-gain instrument [70].

The SKD-0 moving-coil seismometers (with T_s = 15 sec, D_s = 4.0, S_x = 400 mV/μm at 1 Hz increasing with frequency at 6 to 14 dB/octave at f > 0.01 Hz) are used in the three-component, normal-gain and the vertical-component, low-gain channels. The signals from the seismometers are fed into two-stage, negative-feedback amplifier systems with unspecified low-pass and high-pass filters. The first and second stages of the amplifier system consist of FU 117/3 and FU 117/5 galvanometer phototube amplifiers. The input impedance of the phototube-amplifier system is several dozen kΩ and the input noise is less than 0.05 μV. The noise at the input to the analog-to-digital converter does not exceed 4 mV and is thus less than the voltage represented by the least significant bit, usually given as 3.75 mV [70]. The level of microseisms at the channel output is below 50 mV [71]. The voltage gain of the normal-gain channels at frequencies of 1 Hz and 0.01 Hz is 1.6×10^3 and 3.7×10^4, respectively. The overall dynamic range of the normal- and low-gain channels is 70 dB [70].

Curve 2 in Fig. 46 shows the response curves of one vertical-component and the two horizontal-component channels of the digital seismographs operating at the Triangle network in 1970. These channels, operating at normal gain, record velocities in the frequency range $0.01 \leq f \leq 1$ Hz. Velocity sensitivity at periods $1 \leq T \leq 100$ sec varies

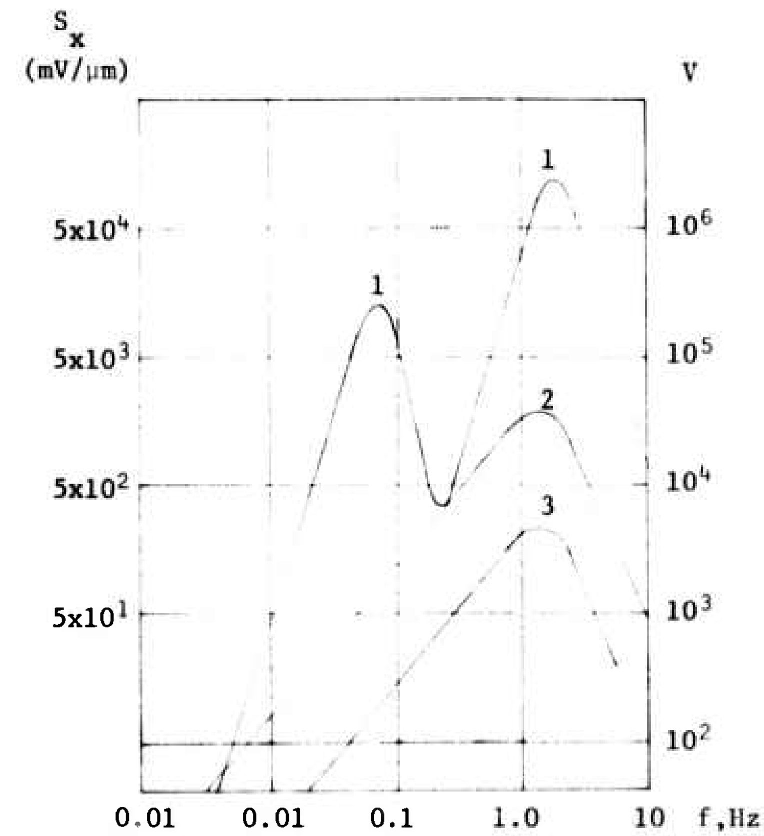


Fig. 46 -- Displacement sensitivity curves of digital seismograph systems operating at the three stations of the Triangle network in 1970 [71]

1 - high-gain, vertical-component channel

2 - one vertical-component channel and two horizontal-component channels operating at normal gain

3 - low-gain, vertical-component channel

S_x = displacement sensitivity at the input to the analog-to-digital converter

V = magnification

between 4 and 8 mV/(μm/sec). The value of the least significant bit of the three normal-gain channels (3.75 mV) at frequencies of 1 Hz and 0.01 Hz corresponds to ground displacements of 4.5 nm and 1 μm, respectively. In units used in Fig. 46, these values correspond to displacement sensitivities of 0.83×10^3 mV/μm at 1 Hz and 3.75 mV/μm at 0.01 Hz. At frequencies $f > 1$ Hz the decrease in displacement sensitivity is 14 to 16 dB/octave while at the low frequency end, $0.005 \leq f \leq 0.01$, the decrease is 12 to 14 dB/octave [70].

The response curves of the low-gain, vertical-component channel shown in Fig. 46 (curve 3) have the same shape as the normal-gain channels. The value of the least significant bit of the low-gain channel corresponds to ground displacements ten times larger and displacement sensitivities ten times smaller than those of the normal-gain channels [70].

An SVKD moving-coil seismometer with T_s = 18 sec, D_s = 0.3, and S_x = 125 mV/μm at 1 Hz, increasing with frequency at 6 to 20 dB/octave is used to record the vertical component of motion at high gain. The signals from the SKD seismometer are fed into a two-stage, negative-feedback galvanometer-phototube-amplifier with the low-pass and high-pass filters described above. Additional gain is achieved by means of the KOD-1 postamplifier. The output noise of the amplifying system is less than 10 mV [70]. The average level of microseisms at the output of the high-gain channel is 200 mV at T = 20 sec and less than 50 mV at other periods [71]. The voltage gain of the high-gain channel is 5×10^5 at 1 Hz, 5×10^3 at 0.15 Hz, and 2.5×10^5 at 0.06 Hz. The dynamic range of the high-gain channel is 60 dB [70].

The response curves of the high-gain, vertical-component channel of the digital seismographs operating at the three Triangle network stations in 1970 is shown in Fig. 46, curve 1. The value of the least significant bit of the high-gain channel (3.75 mV) at frequencies of 1 Hz, 0.05 Hz, and 0.01 Hz corresponds to ground displacements of 0.1 mμm, 1 mμm, and 10.7 mμm, respectively. For curve 1 in Fig. 46 these values correspond to displacement sensitivities of 3.75×10^4 mV/μm at 1 Hz, 3.75×10^3 mV/μm at 0.05 Hz, and 10.7 mV/μm at 0.01 Hz. At frequencies $f > 2$ Hz, the decrease in displacement sensitivity is 22 dB/octave, at $f < 0.05$ Hz, the decrease is 16 to 20 dB/octave, and at the notch (f = 0.18 Hz) the drop is 28 to 30 dB/octave. The ratio of the maximum gain of the high-gain channel at f = 0.06 Hz to that at f = 1.5 Hz is 16. At f = 1 Hz and f = 0.06 Hz, i.e., at the peaks in displacement sensitivity, the system records displacements with amplitudes 0.2 nm to 0.2 μm and 2 nm to 2 μm, respectively [70]. It is interesting to note that the lowest amplitudes given -- 0.2 nm at 1 Hz and 2 nm at 0.06 Hz -- are twice as large as the minimum recordable amplitudes of ground displacements determined from the least significant bit and are probably the true minimum recordable signals for instruments having response curves shown in Fig. 46.

The value of the least significant bit of 3.75 mV corresponds to 2.1×10^{-3} nm of ground displacement at a frequency of 1.5 Hz. The maximum gain at the input to the digital tape recorder is 1.8×10^{8}. The maximum instrumental noise at the output of the analog-to-digital converter at f = 1.5 Hz does not exceed 20 mV (11×10^{-3} nm of ground displacement) [72].

The signals from the postamplifier are sampled sequentially by the scanner of the UDAR-1M analog-to-digital converter, at a rate of 33 samples per second. The analog-to-digital converter is a 10-channel (only 5 are being used) 11-bit successive approximation unit with a dynamic range of ±5 V -- the least significant bit thus represents ~ ±5 mV.* The 5 data channels are recorded in parallel in 11-bit code on 17-track, 35-mm magnetic tape. The 12th bit on the tape is a parity check. The absolute time, converted by a separate unit into a 12-bit code, is recorded at 30-sec intervals, resulting in the loss of data point from each of the 5 channels every 1000 conversions. The 13th bit, placed once every 5 samples, identifies the first channel. The 13th through the 17th tracks identify all five channels once every 500 samples. The packing density is 10 bits/mm at a tape speed of 15.5 mm/sec. A quartz clock, synchronized by radio once every 24 hours, maintains an overall accuracy of 0.1 sec per day [70].

---

*The value of the least significant bit of 3.75 mV quoted in the paper indicates that the range of the converter is 7.5 V peak-to-peak.

All channels are calibrated by feeding 10-V, step-function-current pulses of 28-msec duration into the damping coils of the seismometers. The transfer functions of all channels are recorded on each tape and are used to calculate the frequency-response curves of the channels. Transfer functions registered by visual recorders are also compared with standard functions [70].

2. Editing and Processing Systems

The functions of the editing facility are to search the tape at a speed 10 times greater than the recording speed, excerpt the interesting events, and make a digital-to-analog conversion for visual control and analog recording. The tapes of interesting events are sent to a computer-processing facility [70].

Computer processing of selected events is performed in two stages. In the first stage, raw data consisting of a copy of the tape and blocks of data of 30-sec duration taken from the tape and put on punchcards are read into the computer by means of an input device which automates the input. This device includes a tape recorder, electronic components, oscillograph, control panel, and power supply. It (1) searches the tape according to the time codes input from the control panel or by programmed means, (2) inputs into the computer selected data from any combination of channels, and (3) records and indexes the time code at the end of the tape, until the input of subsequent data. When needed, digital-to-analog conversion is made and the data are displayed on an oscillograph. The input rate into the computer is 2500 or 5000 16-bit words per second at a packing density of 10 bits/mm. The tape speed is 250 mm/sec or 500 mm/sec and the total length of the tape is 500 m. Ten thousand values can be input into the computer in a single pass. A special program deletes the data that fails the parity check and converts the remaining data into the proper format [70].

Computer output after first stage processing consists of a copy of the tape of selected events, a catalog of input events on punchcards, a graphic representation, and a numerical designation of data blocks [70].

The second stage consists of computer processing of selected events in accordance with the programs described in [72]. In general, the computer methods used by Soviet seismologists of extracting weak seismic signals generated by underground nuclear explosions from noise have not been described in the geophysical literature. However, an insight into the capabilities of Soviet computers as well as into the limitations that the scarcity of third-generation computers has imposed can be gained from the main parameters of computers known to be used in seismological applications, shown in Table A-1 in Appendix A. Possible improvement in detection capabilities can be estimated from Table A-2, which gives the principal parameters of third-generation Ryad computers. These are closely patterned after the IBM/360 and are being developed by the Soviet Union in cooperation with several East European countries.

C. SHORT-PERIOD, VERTICAL-COMPONENT SEISMOGRAPH STATION NETWORK FOR EARTHQUAKE PREDICTION AT TASHKENT

A four-station, short-period seismograph station network intended primarily for earthquake prediction is presently being completed at the Tashkent Geodynamic Test Site in Uzbek SSR. Each station is equipped with a SVKM-3 vertical-component, short-period seismograph (described in Section I-A-2) and a SBU-V vertical-component, short-period, borehole instrument operating at a maximum gain of $5 \cdot 10^3$ (see Section I-E-10).* The seismic data from the Chengel'dy (41°51'N, 68°59'E), Yangiyul' (41°06'N, 69°03'E), and Yangibazar (41°19'N, 69°32'E) are telemetered to the Tashkent Seismological Observatory (41°20'N, 69°18'E), which also serves as the fourth station of the network. Three of the stations form a right-angle triangle with sides 30, 40, and 50 km long. The Tashkent Observatory is located at the center of the triangle at a distance of up to 33 km from the other stations [73].

---

*The data from only one seismometer can be telemetered to the central station at any particular time.

A block diagram of the telemete system that has operated since September 1970 is shown in Fig. 47. Off-the-shelf PPS-1M radio transmitters operating from commercial power lines, incorporating channel miltiplexing and FM modulation, are used for data transmission. The technical specifications of the telemetering system are as follows [73,74]:

Modulation type	FM
Frequency response	0.5 to 10 Hz
Carrier frequency	60 to 69, 975 MHz
Dynamic range	40 dB
Nonlinearity	0.5 to 1.0%
System noise referred to the input	0.3 μV
Operating temperature	-15°C to +45°C
Transmission range	30 to 50 km
Receiver sensitivity	2 μV
Power supply	250 W

At present, data from only one of the seismometers at each of the four stations can be transmitted to the Tashkent Observatory at one time; these data are recorded in analog form by a PVZ-T, four-channel, ink-pen recorder at a speed of 240 mm/min [72]. However, when completed, the data channels will be connected to a preliminary-processing system. The signals fed into this system are to be amplified, sampled sequentially by a scanner of an analog-to-digital converter at a rate of 50 samples per second, and recorded in parallel in signed, 8-bit binary code on one of two tape loops with 60-sec memories. An unspecified device (1) scans the data on the magnetic loop that is recording the signals, (2) selects and rerecords significant events, i.e., signals in a specified frequency range with amplitudes at least twice as large as those of the noise background, and (3) automates the data input into a Minsk 22 computer for further processing and analysis [75].

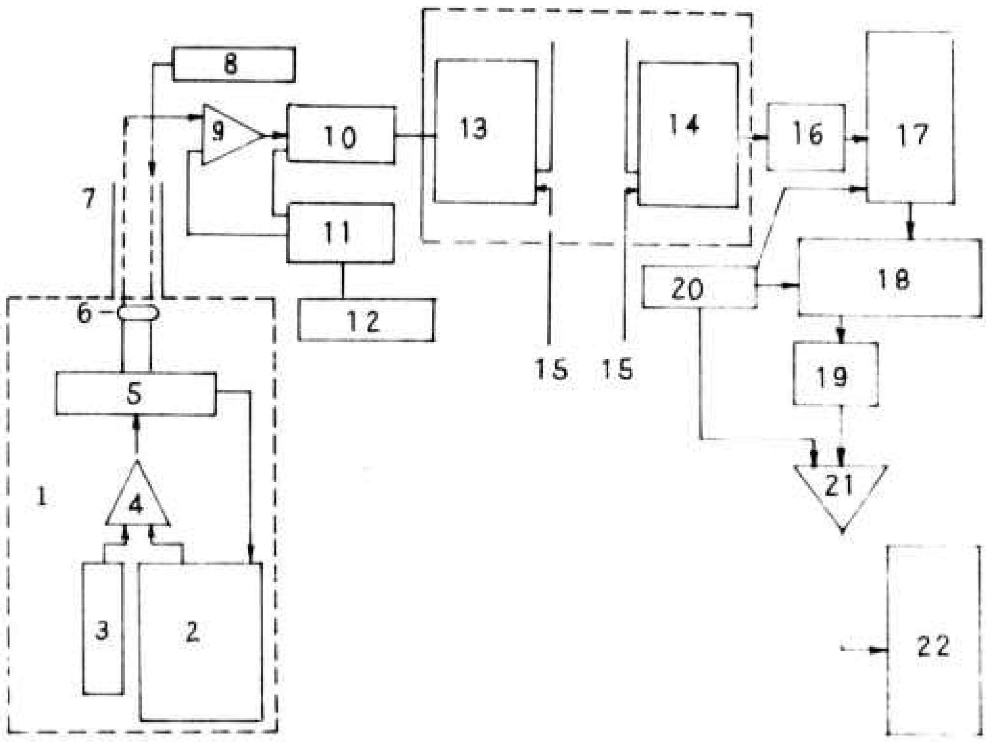


Fig. 47 -- Block diagram of the telemetering system deploying the SBU-V borehole seismometer [73]

1 - borehole package
2 - SBU-V seismometer
3 - battery
4 - parallel-voltage-and-current, double-loop, negative-feedback preamplifier
5 - lightning protection device
6 - cable
7 - borehole
8 - calibrator
9 - amplifier
10 - modulator
11 - voltage stabilizer
12 - battery
13 - PPS-1M transmitter
14 - receiver
15 - current from power lines
16 - filter
17 - amplifier/limiter
18 - converter
19 - filter
20 - battery
21 - power amplifier
22 - PVZ-T four-channel, ink-pen recorder or a preliminary-processing facility

D. THE SHORT-PERIOD, VERTICAL-COMPONENT SEISMOGRAPH STATION NETWORK AT ALMA-ATA

The six-station,* short-period, vertical-component seismograph station network at Alma-Ata is intended primarily for investigation of local seismicity of the region near the city of Alma-Ata. The location of the six stations of the network, the names of the instruments deployed at the stations and their gains, and other pertinent data are summarized in Table 7 [76]. Except that there are six rather than four stations in the network and these are equipped with SBU-V and SM-2M rather than SBU-V and SVKM-3 seismographs, which operate at a much higher gain (3×10^5 to 10^6 rather than 5×10^3), the Alma-Ata network is identical to the Tashkent network described in the previous section.

The magnification curves of the SM-2M and SBU-V seismographs operating at the Alma-Ata network stations are shown in Fig. 23 and Fig. 26, respectively [30]. The use of integrating circuits made it possible to obtain magnification curves flat between 2 and 8 Hz [76]. The SM-2M and SBU-V seismometers, PVZ-T recorder, and the telemetering system used in the Alma-Ata network are described in detail in Sections I-A-6, I-E-10, and I-D-2, respectively. The preamplifier packaged with the SBU-V and SM-2M seismometers and the components of the telemetering system are described in considerable detail in [77]. Since the response of the preamplifier is flat at temperatures up to only 45°C, the SBU-V seismometers are not lowered into the boreholes to depths exceeding 1000 to 1200 m [76]. Two of the borehole stations of the network (Alma-Ata, Ali) are also equipped with short-period ChISS seismographs similar to those which will be described in the next section.

In addition to being recorded in analog form by PVZ-T recorders, the seismic data transmitted to the Novo-Alekseyevskaya Central Station are also digitized on the UDAR-1M analog-to-digital converter and recorded on magnetic tape. While computer time for further processing of seismic data is available, it appears that at present the digitized

---

*A seventh station, Kurty, is mentioned in [76], but since it is 100 km away from the Novo-Alekseyevskaya Central Station and thus well outside the transmission range of the telemetering system (≤ 50 km), it cannot be part of the network.

Table 7 [76]

STATION LOCATIONS AND PRINCIPAL CHARACTERISTICS OF SEISMOGRAPHS AT THE ALMA-ATA NETWORK

Station	Seismograph	Maximum Gain	Seismometer Site	Distance to and Direction Toward Central Station	Remarks
Novo-Alekseyevskaya ~43.4°N, ~77.2°E	SBU-V T_s = 1 sec	--	5-inch, cased, 3000-m borehole	0	Central Station of the network
Alma-Ata ~43.3°N, ~77°E	SBU-V T_s = 1 sec	3×10^5 (day) 6×10^5 (night)	3200-m borehole, cemented at 2000 ft	25 km ~E30°N	A borehole in NE suburbs of Alma-Ata
Ali	SBU-V T_s = 1 sec	3×10^5 to 9×10^5	5-inch, cased, 804-m borehole	28 km ~N30°E	--
Talgar 43°14'N, 77°14'E	SM-2M T_s = 1 sec	3×10^5 to 4×10^5	120-m shaft	19 km S	Surface station
Ozero	SM-2M T_s = 1 sec	10^6	Shallow hole	45 km ~N30°W	Surface station
Medeo 43°09'N, 77°03'E	SM-2M T_s = 1 sec	--	Surface	33 km ~N35°E	Temporary surface station moved from site to site (near earthquake hypocenters)

seismic data are used for nothing more esoteric than preparation of nomograms for a more accurate determination of epicenters of local earthquakes.

E. OTHER SPECIAL SEISMOGRAPH STATION NETWORKS

There may be other special networks of seismographic stations that are similar to those just described. There may also be more sophisticated special networks under construction or in planning stages in different republics of the Soviet Union.

An author's certificate [78], for example, was granted late in 1971 to a group of Siberian seismologists for a seismograph station network deploying multichannel data transmission (see Fig. 48 for a block diagram of the proposed seismograph station network). The seismic data acquired by three seismometers at each station are amplified and the signals from the amplifiers are frequency modulated by three subcarrier frequencies and then are filtered to eliminate crosstalk. The signals are subsequently mixed and transmitted by a side-band transmitter to a central station where the input signal and the timing signal are recorded by a data storage device. The seismic signals from the three seismometers are then passed through three band-pass filters (operating at the same subcarrier frequencies), demodulated, and recorded on photographic paper.

Another paper [79] discusses in general terms a rather sophisticated multichannel teletype seismograph network in Armenia that is suitable for earthquake prediction investigations. It includes up to 70 prognostic sensors and seismometers, installed at five stations, and a computer to analyze seismic data.

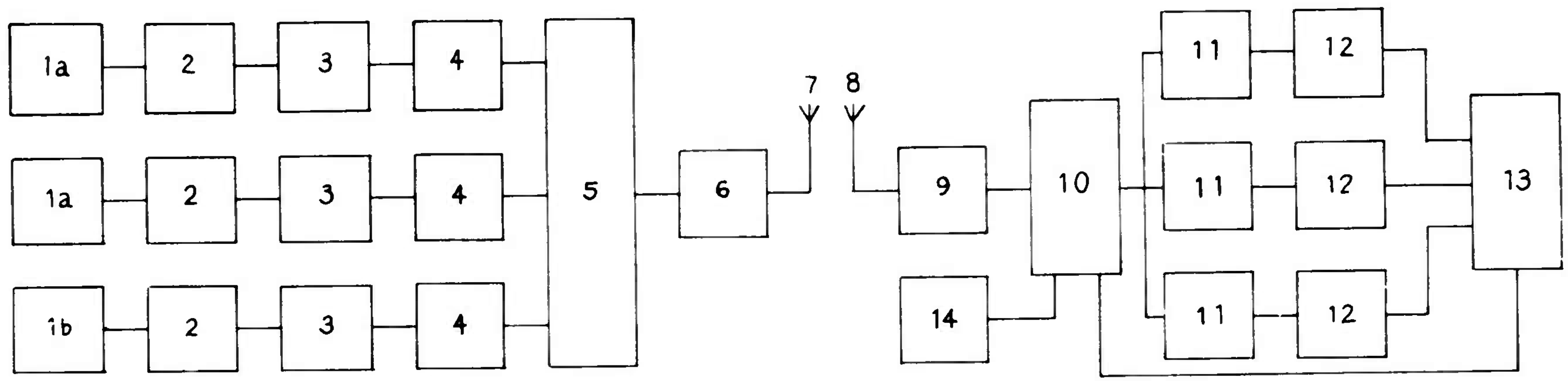


Fig. 48 -- Block diagram of the proposed Siberian station network [78]
(Power supplies are not shown)

1a - horizontal seismometer
1b - vertical seismometer
2 - amplifier
3 - frequency modulator
4 - subcarrier frequency filter
5 - mixer
6 - single-band transmitter
7 - directional antenna
8 - receiving antenna
9 - receiver, including detectors and amplifiers
10 - data storage device
11 - channel filter
12 - demodulator
13 - light-beam oscillograph
14 - timing unit

IV. ChISS AND PSS MULTIPLE-BAND-PASS SPECTRAL ANALYZING SEISMOGRAPHS

A. SHORT-TO-INTERMEDIATE PERIOD ChISS SEISMOGRAPHS

The short-period, photographically recording, multiple-band-pass ChISS seismographs are intended primarily for determining velocity spectra. They usually consist of (1) a short-period, vertical seismometer, (2) a variable gain, broadband amplifier, (3) band-pass channel filters, and (4) a light-beam oscillograph. Although several different models of short-period ChISS seismographs have been developed, in performance they differ mostly in the number and passband of their channels.

A typical short-period, spectral analyzing ChISS seismograph described in [80] is the seven-channel, vertical-component instrument deployed in the early 1960s at Talgar and several other Soviet seismographic stations. The transducer is the SVKM-3 vertical seismometer with T_s = 4 sec and D_s = 0.55, driving a variable gain, broadband ac amplifier with unspecified gains. The amplifier output is fed simultaneously to seven LC filters each having a one-half octave passband and a skirt-slope of 24 dB/octave. The filter settings (high-pass and low-pass critical frequencies) and center frequencies of the ChISS seismograph at the Talgar station are given below and the velocity sensitivity curves of this instrument are shown in Fig. 49.

Channel	Filter Settings (Hz)	Center Frequency[a] (Hz)
1	0.24 to 0.40	0.40
2	0.55 to 0.84	0.80
3	1.1 to 1.7	1.5
4	2.2 to 3.3	2.7
5	4.6 to 7.0	5.7
6	9.2 to 14	11
7	18 to 29	22

[a]Determined from seismograms of local earthquakes.

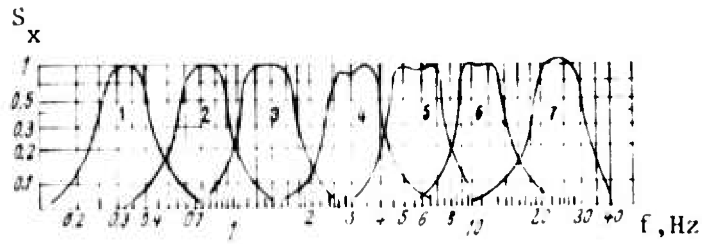


Fig. 49 -- Velocity sensitivity curves of the short-period, vertical-component ChISS seismograph deployed at the Talgar station in the early 1960s [80]

Later models of this seismograph were transistorized and drew 6 to 10 mA at 6 volts.

In 1958 Soviet seismologists set up a special station at Moscow -- Moscow-1 or ChISS-Moscow -- to test and evaluate new models of spectral analyzing seismographs and to improve their performance. Since the early 1960s most of the station's design efforts have been concentrated on developing low-noise, long-period amplifiers and filters for ChISS systems operating at longer periods [81].

The velocity sensitivity curves of a short-period, seven-channel, vertical-component ChISS seismograph used in detection and identification of nuclear explosions are shown in Fig. 50 [64]. This model, operating at somewhat longer periods than the one at Talgar, was deployed at the Moscow-2 station during the early 1960s [82]. The center frequencies of the six channels of this system (given in [64]) and the approximate maximum gain of each channel of the system (determined from Fig. 50) are as follows:

Channel	T_{max} (sec)	Maximum Gain
1	0.2	~300,000
2	0.5	~90,000
3	0.8	~60,000
4	1.6	~18,000
5	2.5	~6,000
6	5	~2,000
7	1.0 to 11	--

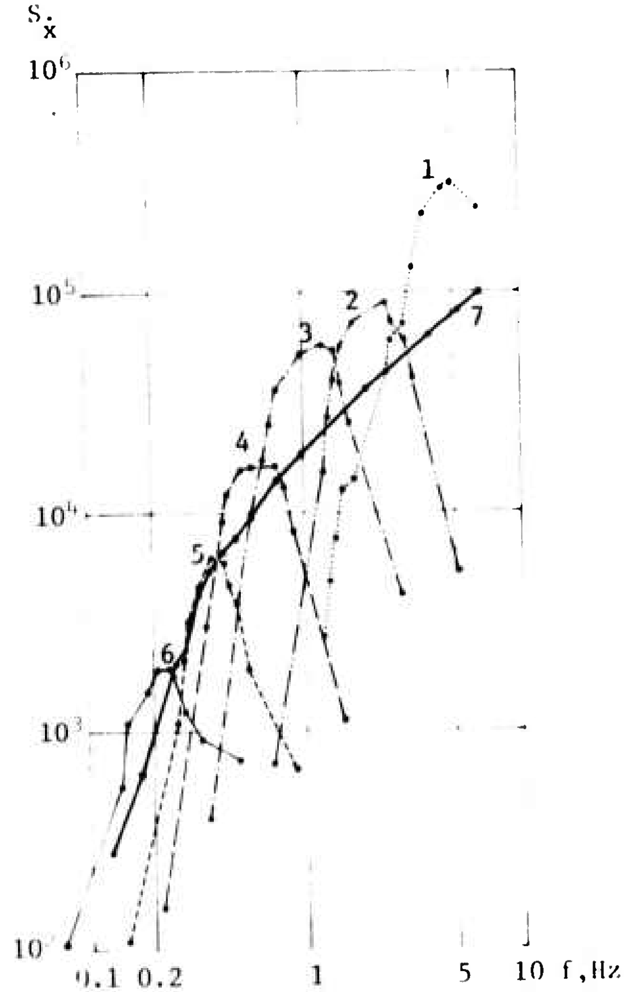


Fig. 50 -- Velocity sensitivity curves of the short-period, seven-channel, vertical-component ChISS seismograph deployed at the Moscow-2 station during 1963-1965 for detection and identification of nuclear explosions [64].

Another slightly different intermediate-band, six-channel, three-component ChISS system was operated at the Moscow-1 and Sochi stations in the early 1960s. In this system the short-period SKM-3 seismometer was replaced with an SK seismometer with T_s = 12.5 sec. The only data available on this system are as follows [82,83]:

Channel	Filter Settings (sec)	Maximum Gain
1	0.9 to 1.6	10,000
2	1.3 to 2.3	--
3	2.3 to 3.7	--
4	3.7 to 7.0	--
5	7 to 11	250
6	1 to 11	--

B. LONG-PERIOD ChISS AND PSS SEISMOGRAPHS

1. ChISS-DVO-25 Seismograph [81]

The ChISS-DVO-25 is a 12-channel, spectral analyzing seismograph consisting of an SVKD-O vertical or SGKD-O horizontal seismometer with T_s = 20 to 25 sec coupled with an F117/8 galvanometer phototube preamplifier, a three-stage postamplifier, eight LC filters each having an octave passband, and a light-beam oscillograph equipped with GB-III or GB-IV galvanometers. In addition to the eight filtered outputs, the system also records four channels of broadband data, including one at low gain.

A block diagram of the ChISS-DVO-25 seismograph and the frequency response curves of its individual components are shown in Fig. 51. The various components of each channel are very loosely coupled so that the overall response of each channel is determined by the product of the responses of each component. The ChISS-DVO-25 can be operated with either the preamplifier or the postamplifier by itself, without either amplifier, or with the preamplifier and two of the three stages of the postamplifier. When operated under stationary conditions the postamplifier is usually replaced with another galvanometer phototube amplifier. The technical specifications of the F117/8 phototube amplifier given in [81] are as follows:

Internal noise .... $(1-2)\cdot 10^{-2}$ μV

Peak output signal .... 7 V

Maximum gain 2000

Peak input signal .... 3.5 mV

Sensitivity .... $(4-5)\cdot 10^{-2}$ μV

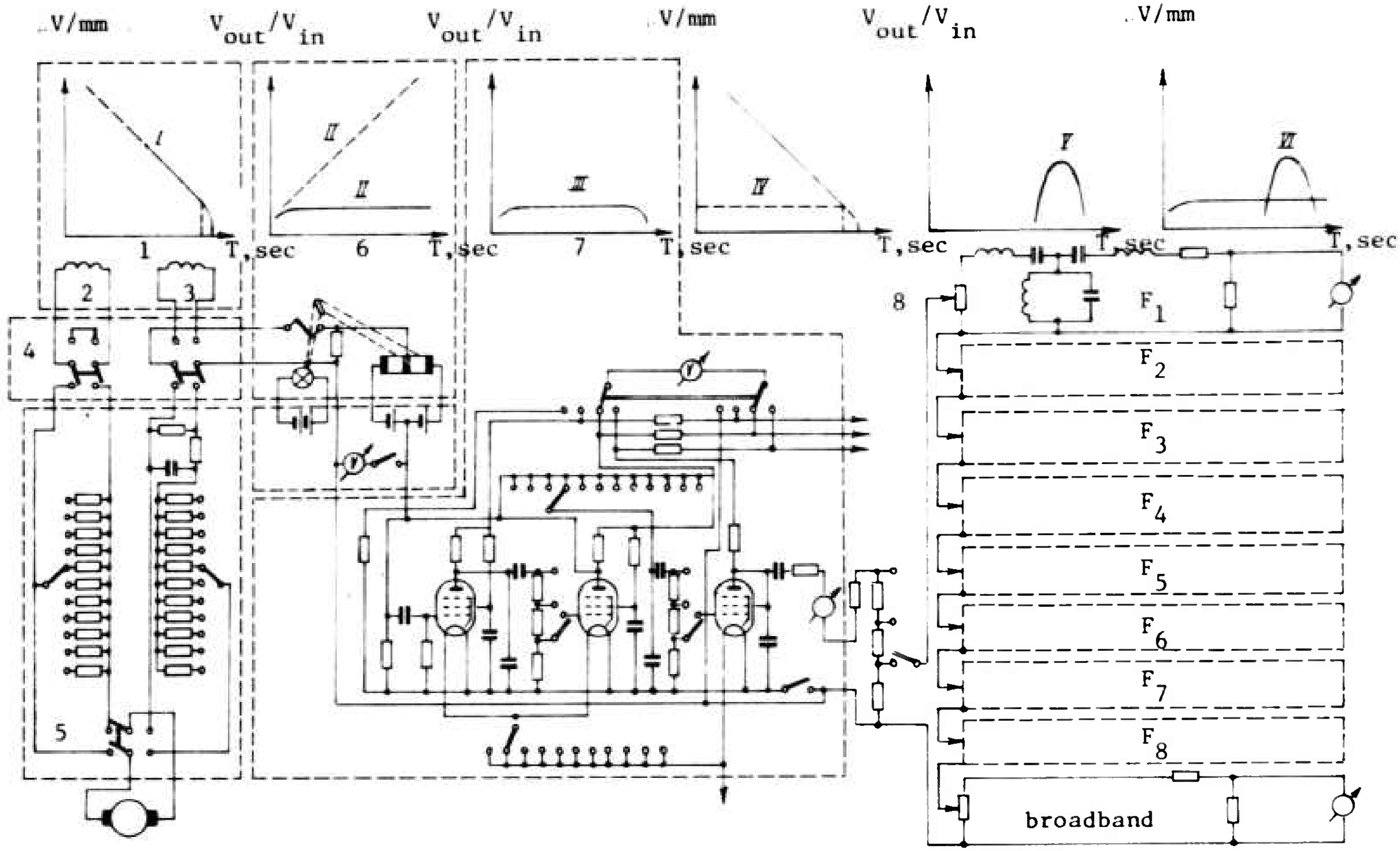


Fig. 51 -- Block diagram of the ChISS-DVO-25 seismograph and the response-curves of its individual components [81]

1 - seismometer 5 - calibration unit
2 - damping coil 6 - galvanometer phototube preamplifier
3 - signal coil 7 - postamplifier
4 - control panel 8 - LC filters
I-VI -- response curves of the individual components of the ChISS-DVO-25 system

The gain of the first two stages of the postamplifier is about 2000, its internal noise is 1 μV, and the peak input signal at full gain is 250 μV.

Theoretically calculated velocity sensitivity curves of the ChISS-DVO-25 seismograph are shown in Fig. 52. The high-pass and low-pass critical frequencies and also the actual operating gain of some of the channels are:

Channel	Filter Settings (sec)	Maximum Gain[a]
1	0.12 to 0.25	--
2	0.25 to 0.50	--
3	0.50 to 1.0	--
4	1 to 2	12,000
5	2 to 4	3,000
6	4 to 8	900
7	8 to 16	4,000
8	12 to 25	4,000

[a]Gain at which these channels were operating at the ChISS-Moscow station.

Very few data are available on the ChISS-DVO-25 seismograph; it appears, however, that the operating model is a six-channel system, one broadband and five filtered outputs (channels 4 to 8 in the listing given above). The somewhat idealized response curves of a six-channel ChISS system operating at the Sochi station in the mid-1960s, which almost certainly is the ChISS-DVO-25 seismograph, is shown in Fig. 53.

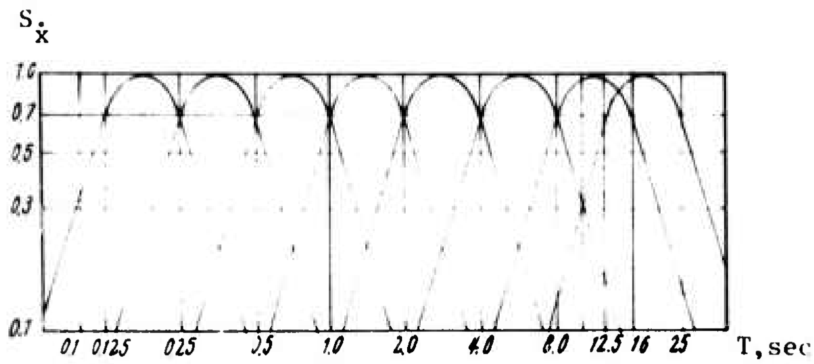


Fig. 52 -- Theoretically calculated velocity sensitivity curves of the ChISS-DVO-25 seismograph [81]

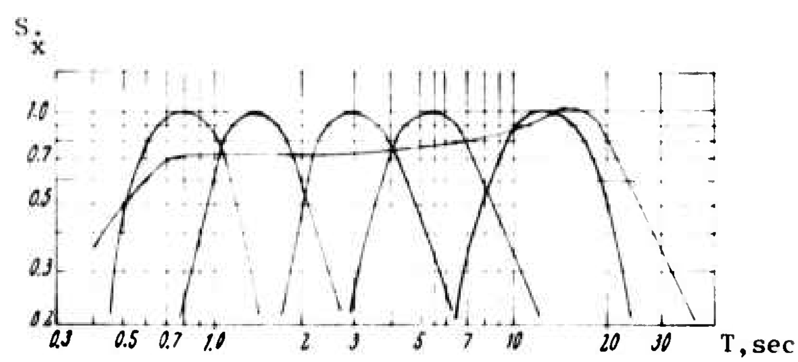


Fig. 53 -- Somewhat idealized velocity sensitivity curves of the ChISS-DVO-25 seismograph operated at the Sochi station during the late 1960s [84]

2. ChISS-DVO-128 Seismograph [81]

The ChISS-DVO-128 vertical-component seismograph is a ten-channel (eight filtered outputs of octave bandwidth and two broadband outputs) spectral analyzing seismograph. The period range of the ChISS-DVO-128 extends over the bandpass 0.5 and 128 sec. The ten channels can be subdivided into two separate groups: (1) intermediate band (0.5 to 1 sec, 1 to 2 sec, 2 to 4 sec, 4 to 8 sec, and 8 to 16 sec) and one broadband (0.5 to 20 sec) and (2) the long-period (16 to 32 sec, 32 to 64 sec, and 64 to 128 sec) and one long-period broadband (16 to 128 sec). A schematic block diagram of the ChISS-DVO-128 seismograph is shown in Fig. 54. Both groups of channels operate from the same

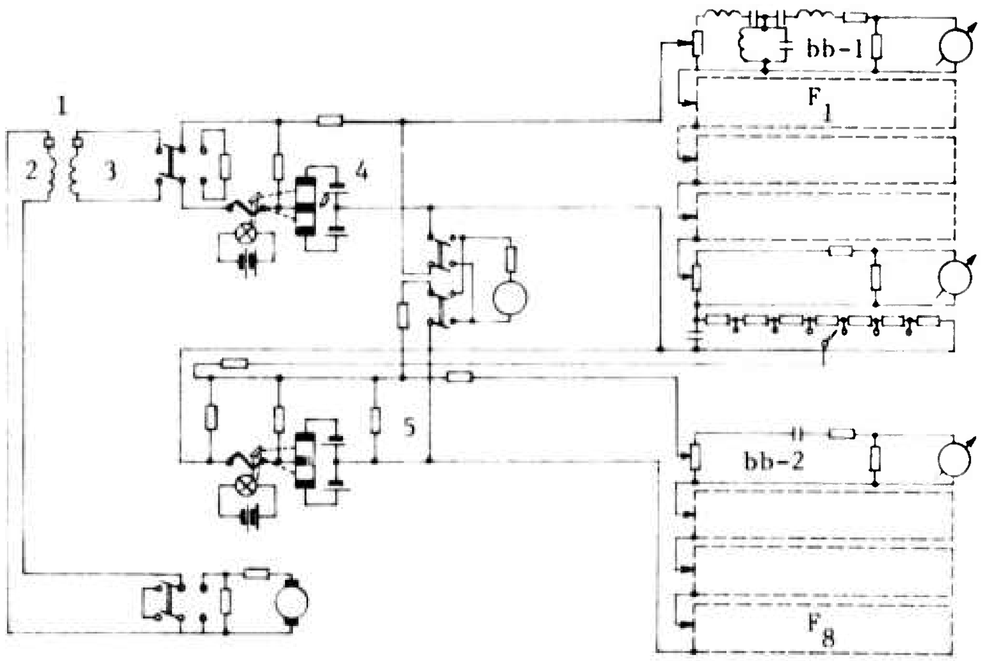


Fig. 54 -- Schematic block diagram of the ChISS-DVO-128 seismograph [81]
1 - SVKD seismometer
2 - damping coil
3 - signal coil
4 - FU 117/7 or F117/8 galvanometer phototube amplifier
5 - FU 117/5 galvanometer phototube postamplifier
F_1 to F_8 - LC filters
bb-1 and bb-2 - broadband channels

SKD-0 seismometer. The part of the ChISS-DVO-128 seismograph system that shapes the frequency response of six of the shorter period channel outputs is similar to that of the DVO-25, but has only five instead of eight LC filters. The remaining three very-long-period filter outputs and one broadband output are formed by feeding part of the signal from the first galvanometer amplifier through an RC-integrating network and into a second, an F117/5 galvanometer phototube amplifier, with a gain of (3 to 5) x 10^5 operated in an integrating mode. The LC filters are also similar to those in the ChISS-DVO-25. Output circuits of the broadband channels of the postamplifier provide drift compensation at very long periods. Theoretically calculated velocity sensitivity curves of the ChISS-DVO-128 are shown in Fig. 55. Figure 56 shows the

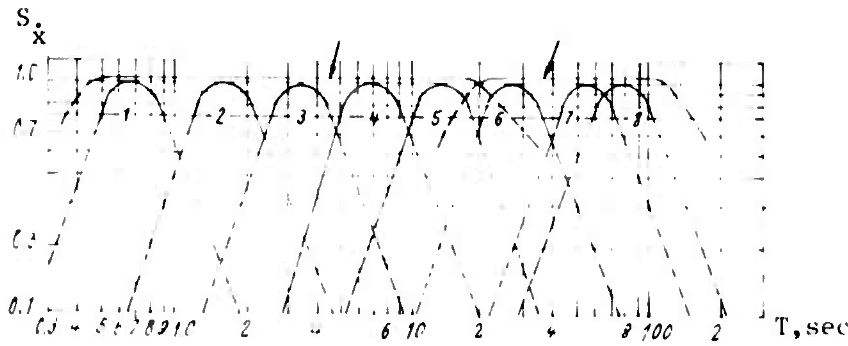


Fig. 55 -- Theoretically calculated velocity sensitivity curves of the ChISS-DVO-128 seismograph [81]

actual velocity sensitivity curves of the ChISS-DVO-128 seismograph operating at the Obninsk station in 1971.

3. PSS Seismograph

Two velocity sensitivity curves of PSS spectral analyzing band-pass seismographs are shown in Figs. 56 and 57. While no data are available on this seismograph it appears to be the same system as that described in [85] and thus very similar to the ChISS instrument. The seismograph described in [85] consists of an SVKM-3 seismometer with T_s = 3.5 sec, D_s = 0.7, coil resistance R_s = 80 ohms; a two-stage FI-2 galvanometer phototube amplifier consisting of two uncoupled, slightly modified F117/10 phototube amplifiers operating in integrating mode, achieved by heavily overdamping the galvanometer; and LC filters loaded with GB-III-B-5 galvanometers. The principal characteristics of the slightly modified F117/10 phototube amplifiers that are incorporated in the two-stage FI-2 amplifier system are:

Natural period .... 2.5 sec
Damping factor 65
Time constant .... 200 sec
Range of integration .... 3 to 200 sec
Input noise .... 10^{-9} V
Input impedance .... 1.1 kohms
Dynamic range .... 78 to 98 dB
Maximum gain .... 5×10^6

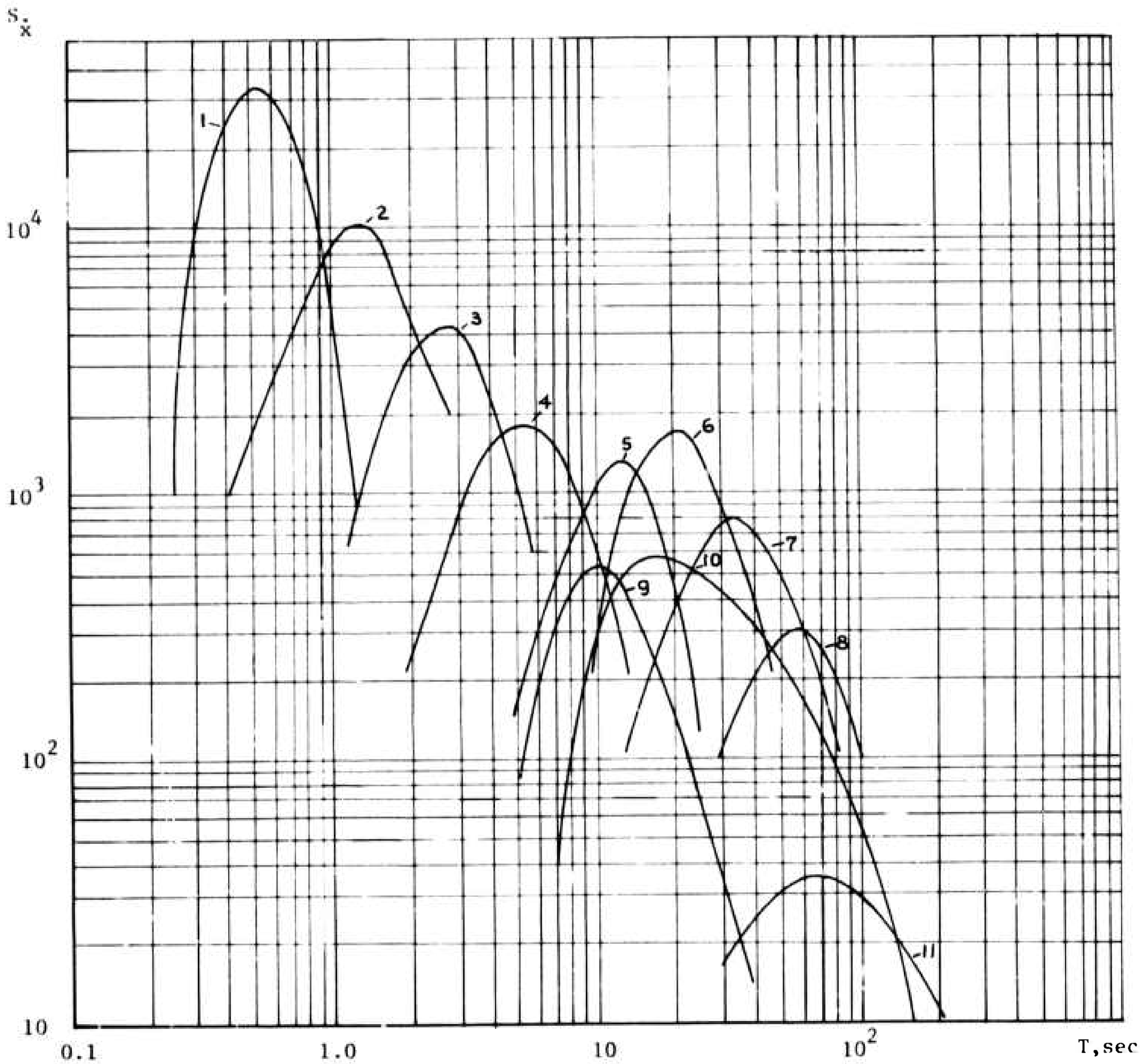


Fig. 56 -- Velocity sensitivity curves of the ChISS-DVO-128 (curves 1 through 8) and PSS (curves 9 through 11) seismographs operating at the Obninsk station in 1971 [58]

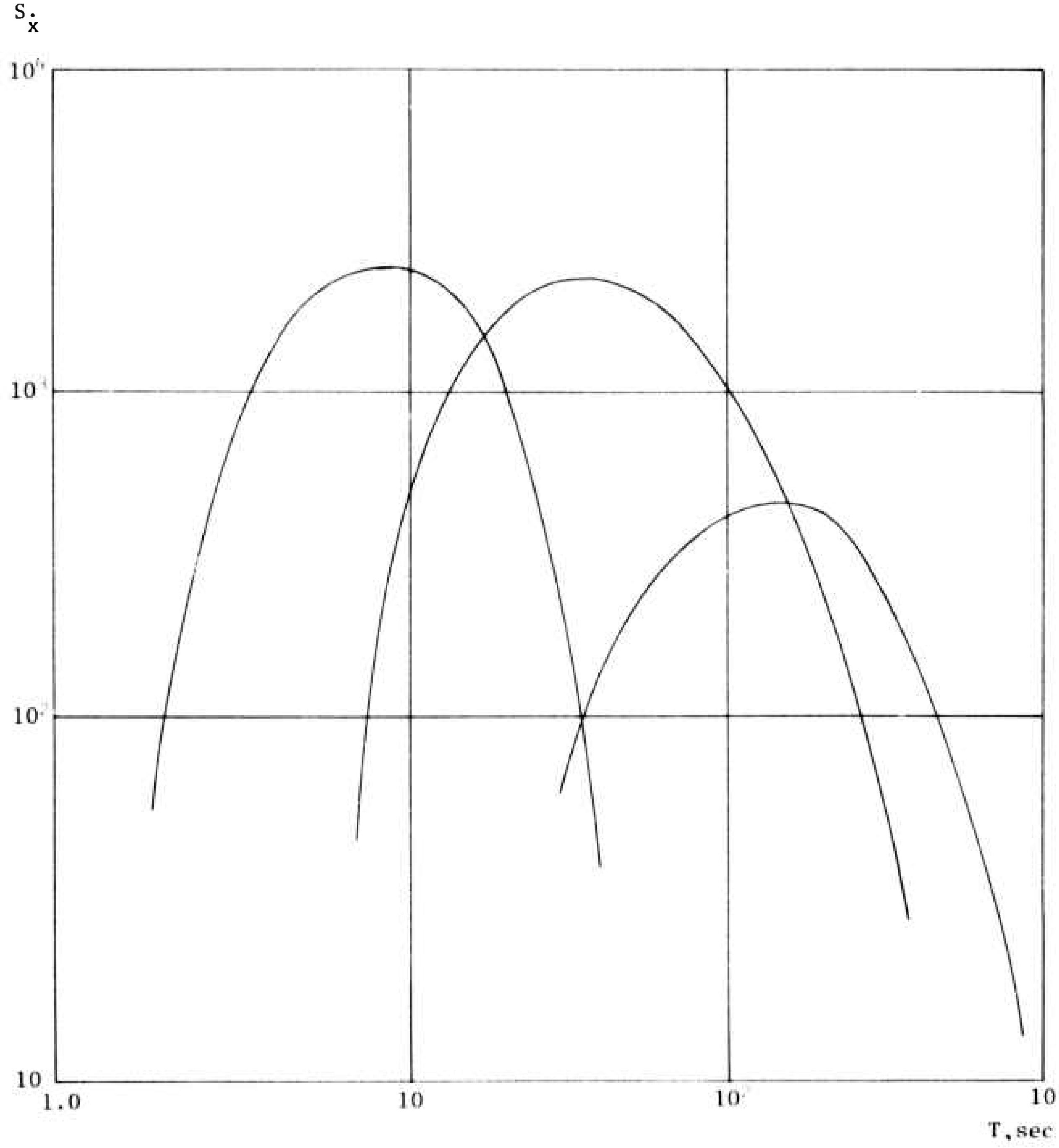


Fig. 57 -- Velocity sensitivity curves of the PSS system operating at the Sochi station during the late 1960s [84]

The original PSS model was to be a four-channel velocity or displacement seismograph with the following filter settings and gains:

Channel	Filter Setting (sec)	Maximum Gain
PSS Velocity Meter		
1	4.5 to 20	$2 \cdot 10^3$
2	20 to 90	$1.4 \cdot 10^3$
3	60 to 230	$1.1 \cdot 10^3$
4	140 to 600	$3.5 \cdot 10^2$
PSS Displacement Seismograph		
1	6 to 25	$2 \cdot 10^3$
2	20 to 90	120
3	50 to 190	16
4	160 to 700	1

The basic differences between the PSS and the three long-period channels of the DVO-128 band-pass seismographs are (1) the seismometers (short-period SKM-3 in the PSS and long-period SKD-0 in the ChISS-DVO-128) and (2) the improved galvanometer phototube-amplifiers in the PSS (F117/10 in the first and second stages of the PSS versus the older F117/7 or F117/8 in the first stage of the ChISS-DVO-128 and the F117/5 in its second stage).

V. LONG-BASE STRAINMETERS

A. GENERAL

Since 1961 Soviet geophysicists have installed long quartz-tube strainmeters at several Soviet geophysical stations. The locations and the principal parameters of these instruments are given in Table 8. Except for the strain seismographs in operation at Obninsk, all Soviet strainmeters are similar to those installed at the Kondar seismograph station.

B. THE STRAINMETER AT KONDAR [86]

The location of the Kondar station and the principal characteristics of the 19-, 18.5-, and 15.5-meter strainmeters operating at this station are given in Table 8. The instruments are housed in an 110-m main tunnel and one of the 20-m side drifts bored in granite in the immediate proximity of a large fracture. The strainmeters are located 40 to 50 m below the ground surface and 70 m from the tunnel opening. The diurnal temperature variations in the tunnel are within 0.01°C. The indicator is composed of 3 m sections of fused quartz tubing welded together. The diameter of the quartz tube is 4 cm and its walls are 2 to 3 mm thick. The piers and supporting members, located at 2.5-m intervals, are made of quick-curing concrete. The quartz tubes are suspended from the supporting members by wire slings. A magnetostrictive calibrator is inserted between two sectors of quartz tubing near the fixed end of the indicator.

Two of the strainmeters at Kondar are equipped with identical magnifying systems that consist of a roller located between the free end of the quartz tube and a highly polished surface. Displacement of the quartz tube turns the roller, which deflects the light beam incident on a mirror mounted on the roller. The third strainmeter is equipped with a roller and a double-bow string, or a similar magnifying system, not in use with any other Soviet strainmeters.

Table 8

PRINCIPAL CHARACTERISTICS OF SOVIET LONG-BASE STRAINMETERS

Station	Length (m)	Orientation	Magnifier	Amplifier	Recording Method	Recorder Sensitivity (μm/mm)	Strain Sensitivity ($x10^{-8}$/mm)	Recording Speed (mm/hr)
Childara [87] 38°47'N, 70°18'E h[a] = 50 to 70	20 to 25	S15°E	Roller	--	Direct optical	--	~1.0	--
			Roller	Phototube	Galvanometric	--	~0.1	
			Roller	--	Direct optical	--	~1.0	--
	20 to 25	W15°S	Roller	Phototube	Galvanometric	--	~0.1	
Chusal [87] ~39°05'N, 70°55'E h = 50 to 70	20 to 25	N12°E	Roller	--	Direct optical	--	~1.0	--
			Roller	Phototube	Galvanometric	--	~0.1	
			Roller	--	Direct optical	--	~1.0	--
	20 to 25	E20°S	Roller	Phototube	Galvanometric	--	~0.1	
Dzherino [88] ~38.7°N, ~68.5°E	20	S15°W	Roller	Phototube	Galvanometric	0.3	0.15	22
	20	E15°S	Roller	Phototube	Galvanometric	0.05	0.31	22
			Roller	Phototube	Galvanometric	0.05	0.25	
Garm [87] 39°00'N, 70°19'E h = 50 to 70	20 to 25	N-S	Roller	--	Direct optical	--	~1.0	--
			Roller	Phototube	Galvanometric	--	~0.1	
			Roller	--	Direct optical	--	~1.0	--
	20 to 25	E-W	Roller	Phototube	Galvanometric	--	~0.1	
Inkerman [89] 44°36'N, 33°36'E h = 80 m	12.46	N6°29'W	Roller	--	Direct optical	--	0.8	--
			Roller	Phototube	Galvanometric	--	~0.8	
	7.78	N82°31'W	Roller	--	Direct optical	--	0.8	--
			Roller	Phototube	Galvanometric	--	~0.08	
Kondar [86] ~38.5°N, ~68.8°E h = 40 to 50 m	18.5	E15°S	Roller	--	Direct optical	0.13	0.7	--
			Roller	Phototube	Galvanometric	0.02	0.1	
	19	E15°S	Roller	--	Direct optical	0.15	0.8	--
			Roller	Phototube	Galvanometric	0.04	0.2	
	15.5	S15°W	Bow string	--	Direct optical	0.25	1.6	--
			Roller	Phototube	Galvanometric	0.05	0.3	

Table 8 (cont.)

Station	Length (m)	Orientation	Magnifier	Amplifier	Recording Method	Recorder Sensitivity (μm/mm)	Strain Sensitivity ($\times 10^{-8}$/mm)	Recording Speed (mm/hr)
Obninsk [90] 55°10'N, 36°27'E h[a] = 30 m	34	N-S	Slit Moving coil	Phototube --	Galvanometric Galvanometric	-- --	0.07 See Fig. 61	120
	34	E-W	Slit Moving coil	Phototube --	Galvanometric Galvanometric	-- --	0.1 See Fig. 61	120
Protvino [91,92] 54°52'N, 37°14'E h = 16 m	17.3 17.5	N-S E-W	Roller Roller	Phototube Phototube	Galvanometric Galvanometric	0.01 0.01	0.1 to 0.01 0.1 to 0.01	90
Talgar [88,93] 43°14'N, 77°14'E h = 50 m	26	N-S	Roller Roller	-- Phototube	Direct optical Galvanometric	0.2 0.01	0.8 0.04	90
Tbilisi [94,95] 41°43'N, 44°47'E h = 50 m	42 14.5	N60°E N30°W	Roller Roller	-- --	Galvanometric Galvanometric	0.08 0.1	0.22 0.7	--
Toktogul [96] 41°50'N, 72°50'E	--	--	--	--	--	--	--	--

[a]h is the depth below the ground surface.

One of the magnifying systems of each strainmeter is used for direct photographic recording. The formula for determining the beam deflection, d, on the film is $d = 2L(S/D)$, where L is the optical lever, S the displacement, and D the diameter of the roller (equal to 4 mm). The light beam from the second magnifying system is incident on the splitter lens assembly of a phototube amplifier driving a recording galvanometer. A smoothed out plot of tidal strains recorded by the strainmeters at Talgar, Garm, and Kondar stations is shown in Fig. 58.

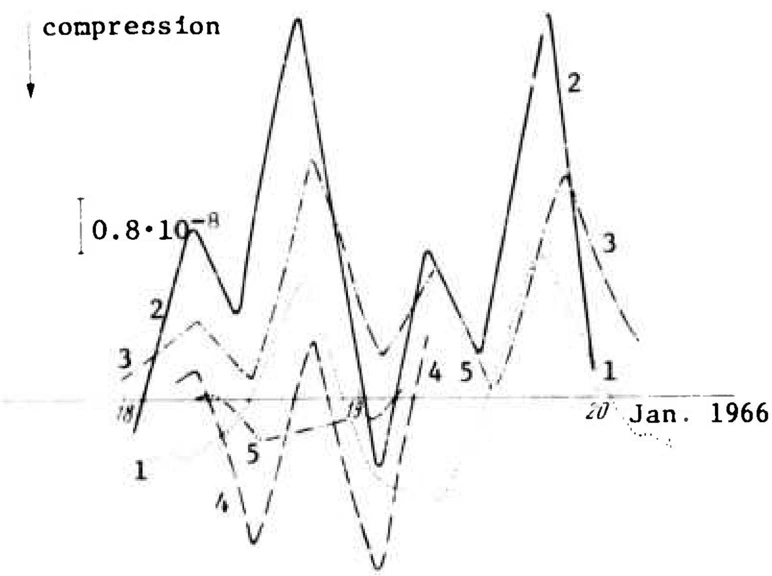


Fig. 58 -- Tidal strains recorded by the following strainmeters [86]:
1 - Kondar, E15°S component
2 - Kondar, S15°W component
3 - Talgar, N-S component
4 - Garm, N-S component
5 - Garm, E-W component

C. THE STRAIN SEISMOGRAPH AT OBNINSK [90]

The principal characteristics of the 34-m-long strainmeters operating at Obninsk are given in Table 8. The indicator consists of 1.6 to 1.8 m fused quartz tubing with an outer diameter of 7.0 to 7.7 cm and walls 0.8 to 1.0 cm thick, joined by invar flanges. The strainmeter is equipped with an electromagnetic calibrator.

Each strainmeter has two separate channels. The secular strains and tilts are recorded with the aid of a 0.5-mm-wide slit on a screen attached to the quartz tube. A light beam transmitted by the slit is incident on the photocell assembly of a phototube amplifier, which drives the recording galvanometer. An overdamped galvanometer with $T_g = 6$ sec is used to eliminate short-period noise.

The seismic data are acquired by another channel formed by a standard, moving-coil (velocity) transducer of the SKM-3 seismometer wound with 3000 turns of coil which drives a 100-sec DG-100I galvanometer. The parameters of the transducers and galvanometers used in the two strainmeter channels that record seismic data are summarized in Table 9. The magnification curves of these two channels are shown in Fig. 59. In Table 9, T_g is the galvanometer period, D_g is the damping factor, R_g is coil resistance, CDRX is the external critical-damping resistance, C_i is the current sensitivity, K_g is the moment of inertia, G is the signal-coil generator constant, and R_c is its coil resistance. The recording speed of this channel is 120 mm/min. A record of the N-S component of tidal strains recorded by the Obninsk strainmeter on March 11, 1970, is shown in Fig. 60 [90].

Table 9 [90]

PARAMETERS OF TRANSDUCERS AND GALVANOMETERS OF THE STRAINMETER CHANNEL THAT RECORDS SEISMIC DATA
(as of January 1970)

Compass	T_g (sec)	D_g	R_g (ohms)	CDRX (ohms)	C_i (amp/m at 1 m)	K_g ($gr \cdot cm^2$)	G [v/(m/sec)]	R_c (ohms)
N-S	100	2.4	96.3	1164	4.24×10^{-11}	1.64	168.5	1164
E-W	100	2.4	101.8	1260	3.72×10^{-11}	1.61	187.5	1260

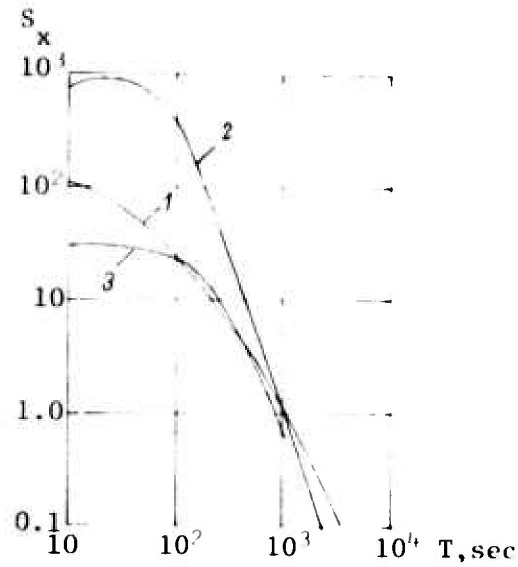


Fig. 59 -- Magnification curves of the strainmeter channels recording seismic data and of the Press-Ewing seismograph [90]
1 - strain seismograph (since 1 Jan 70)
2 - Press-Ewing seismograph
3 - strain seismograph (before 1969)

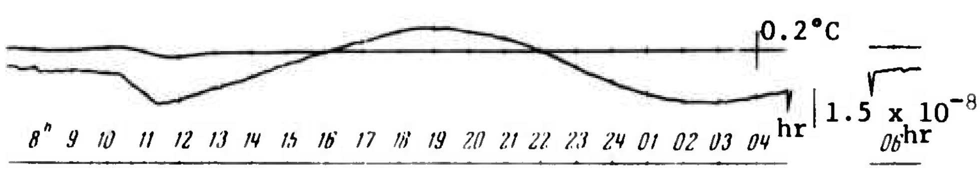


Fig. 60 - Tidal strains as recorded by the N-S component of the Obninsk strainmeter, March 11, 1970 [90]

NOTE: The sudden variation at 1000 hours occurred when the lights in the tunnel were switched on.

VI. AUXILIARY EQUIPMENT

A. TIME SERVICE EQUIPMENT

1. Digital Quartz Clock for Unattended Seismographs [1]

This unnamed digital quartz clock is designed for unattended seismographs operating either in standby or continuously recording mode. A 100-Hz signal, generated by a thermostated quartz crystal oscillator, is fed into a frequency divider; this generates second and minute pulses and inputs them into an unspecified converter which designates binary coded minute marks. The accuracy of the clock is better than ±0.01 sec per 10 days of operation. The quartz clock requires a 3 V and a 12 V dc power source. The dimensions of the components of the quartz clock and their power consumption are as follows:

Frequency divider and encoder
- diameter .... 15 cm
- height .... 4 cm

Thermostat
- diameter .... 13 cm
- height .... 23 cm

Power consumption
- frequency divider .... 0.6 W
- encoder .... 0.8 W
- thermostat .... 0.3 W/°C (at T = 35 to 50°C)

2. PKCh Quartz Clock [1]

The PKCh-2 portable quartz clock is designed to provide precise timing signals for geophysical, including seismological, applications. The PKCh provides hour, minute, second, and 1/100 sec timing marks. The output timing pulses can be synchronized to radio transmitted signals with an accuracy of 0.01 sec. The technical specifications of the PKCh-2 are as follows:

Frequency	
F_0 reference frequency	100 kHz
amplitude	≥0.5 V into a ±10 kohm load
F_1 through F_4	100 Hz, 1 Hz (sec marks), 1/60 Hz (min marks), 1/3600 Hz (hour marks)
Amplitude	5 V into a 100-ohm load
Pulse width	
sec marks	0.1 sec
min marks	1 sec
hr marks	2 sec
Accuracy	≥5%
Output voltage deviation	≥5%
Operating temperature	+10°C to +40°C
Relative humidity	up to 95%
Power supply	110, 127, 220, or 230 V ac or 6 V dc; 25 W

3. I-ZPG-23 Precision Timing System [1,45]

I-ZPG-23 precision timing systems are manufactured in Czechoslovakia and intended for geophysical and astronomical applications and apparently have been installed at no fewer than forty base seismographic stations in the Soviet Union. The I-ZPG-23 provides timing marks at the following time intervals: 0.00001, 0.0001, 0.001, 0.01, 0.02, 0.1, 1 sec; 1 min; and 1 hr. The timing system consists of a 100 kHz thermostated crystal oscillator, a contact closure module, two power amplifiers, and a module for synchronizing the output timing pulses to any real-time function (radio transmitted signals).

The technical specifications of the I-ZPG-23 timing system are as follows:

Frequency	
F_0 reference frequency	100 kHz
F_1 through F_9	10^5, 10^4, 10^3, 10^2, 5×10^1, 10^1, 1, 1/60, 1/3600 Hz
Aging rate	
(first 30 days of continuous operation)	5×10^{-9}/day
(after 1/2 year of continuous operation)	1×10^{-9}/day

Adjustment	Frequency adjustment to compensate for crystal aging for up to 0.5 Hz
Output signal at front panel ...	1 V
Operating temperature	+5°C to +38°C
Temperature stability +15°C to +25°C	5×10^{-10}/°C
Power supply	Two sources: 220 V ac (50 Hz) and 12 V dc, 50 W
Weight	30 kg

4. <u>OAB Absolute Time Marker</u> [1]

The OAB one-channel, absolute-time marker records a coded signal on magnetic tape, photographic paper, or film. When recording begins, the number of the time mark (for example, a minute mark) is registered in code by means of alternating-polarity time marks of the least significant bit (for example, second marks). The OAB can be used with any clock that provides second-and-minute or minute-and-hour pulses. The diameter of the unit is 16 cm and it is only 3 cm high. The OAB draws a current of 300 mA from a 3 V dc source.

5. <u>RFU Time Signal Receiver</u> [1]

The RFU is a receiver of time signals transmitted over the standard broadcast system. The 1000 Hz tone transmitted on the exact hour is of unspecified duration. The receiver is equipped with a regulator, a clipper limiter, and an active 1000 Hz filter. Narrow band-pass and clipper limitation sharply improve the transmitted signal in spite of the noise and broadcasting transmission. The receiver controls the time marks that are printed on seismograms. A clock mechanism in the RFU turns the receiver every hour in order to record the signal automatically. A few of the available specifications of the RFU receiver are as follows:

Input signal	0.1 V
Power supply	12 V dc, 2 W
Dimensions	16 x 13 x 8 cm
Weight	2 kg
Operating temperature	+5°C to +40°C

B. MAGNETIC DRUM RECORDERS AND TAPE LOOPS

1. SZZ Magnetic Drum Recorder [1,97]

The SZZ 6-channel magnetic drum recorder has a 20 sec memory and is intended for registration of teleseismic events without a loss of first motion. It was developed in the early 1960s for use with the standard broadband SK seismometer and the short-period SKM-3 with 1000-ohm signal coil. Below a certain threshold, a magnet continuously erases transducer signals recorded on the drum. Any seismic event above the threshold actuates a heated-stylus recorder or a light-beam oscillograph, which rerecords from the drum without a loss of motion. A block diagram of a seismograph system deploying a SZZ magnetic drum recorder is shown in Fig. 61. Technical specifications of the SZZ magnetic drum recorder used with SK seismometers are as follows:

Number of channels	6
Memory	20 sec
Dynamic range	46 to 50 dB
Modulation type	FM
Center frequency	150 Hz
Percent modulation	±50%
Frequency response (with SK seismometers)	0.2 to 10 sec
Gain (with SK seismometers)	1000
Power supply	12 V dc; 6 V; 30 W
Dimensions	54 x 50 x 50 cm
Weight	40 kg

It is intended for operation at permanent stations at temperatures between +10°C and +30°C and a relative humidity of up to 80 percent.

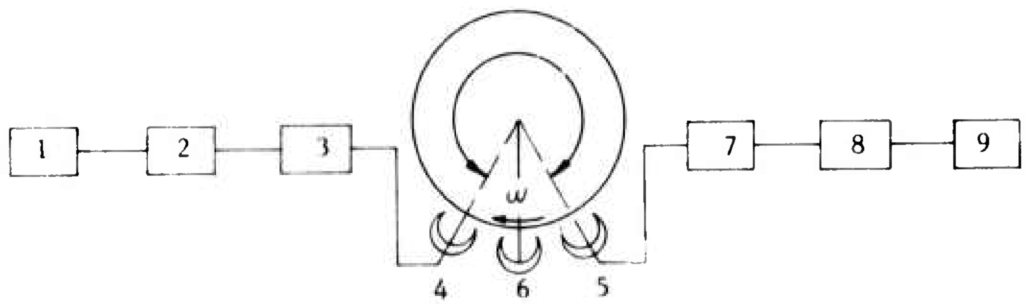


Fig. 61 -- Block diagram of the SZZ magnetic drum recorder [98]
1 - seismometer
2 - preamplifier
3 - modulator
4 - magnetic drum
5 - heads
6 - erasing magnet
7 - demodulator
8 - postamplifier
9 - heated-stylus or light-beam recorder

2. Six-Second-Memory Magnetic Drum Recorder [99]

This unnamed 7-channel magnetic drum recorder with a 6-second memory was developed in the late 1960s for registration of near earthquakes. Its operation is similar to that of the SZZ described in the previous section. The drum recorder was used with VEGIK seismometers with a 1000 ohm signal coil and a modified POB-12M light-beam oscillograph actuated by a seismic trigger. The technical specifications of the recorder are as follows:

Number of channels	7
Memory	6 sec
Modulation type	PFM
Center frequency	300 Hz
Percent modulation	--
Input noise	3 μV

Frequency response	0.1 to 7 Hz
Dynamic range	50 dB
Maximum gain	20,000
Power supply	12 V dc, 4 W, and 50 W
Dimensions	47 x 47 x 52.5 cm
Weight	35.5 kg

3. MZ1 and MZ2 Tape Loop Devices [26]

The MZ1 and MZ2 tape loop devices, with five-minute and one-minute memories, respectively, were developed recently for use with triggered digital seismograph systems that incorporate 17-track tape recorders such as the LMR series used in the KOD seismograph station networks.

C. ANALOG-TO-DIGITAL CONVERTERS

1. F-004 Seismogram Digitizer [1,100]

The F-004 is a multipurpose visual digitizer designed in the early 1960s to convert seismogram traces into ten-bit normalized code, punched on cards, and decimal numbers, punched on paper tape. The digitizer can measure ordinates of traces not exceeding ±7 cm at equal sample intervals, recorded on seismograms up to 30 cm wide and 20 m long. The technical specifications of the F-004 digitizer are as follows:

Sample values	≤ ±7 cm
Maximum sample value error	0.5 mm
Sample intervals	0.1, 0.2, 0.4, 0.8, 1.6, 3.2 ±5%
Screen magnification	1:1 or 3:1 ±10%
Digital potentiometer linearity	≤0.2%
Digital voltmeter accuracy	≤0.5%
Sampling rate	from 1 sample/min to 60 samples/min
Power supply	220 V ac, 50 Hz
Dimensions	80 x 60 x 65 cm
Weight	125 kg

2. UDAR-1M Analog-to-Digital Converter [1]

The UDAR-1M solid-state analog-to-digital converter is a multi-channel successive-approximation unit that converts electrical signals into 11-bit code, recorded in parallel on magnetic tape by an LMR-type recorder. The principal technical specifications of the UDAR-1M digitizer are as follows:

Number of channels	10 (1,2,5)
Input voltage	0 to 10 V
Input impedance	10 kohm
Least significant bit	±5 mV
Output	parallel binary code
Power supply (KOD-III)	9.5 to 10 V, $\leq$0.5 ±1.5 V, ≈0.1 amp
Dimensions	42 x 37 x 50 cm

Originally developed exclusively for use with the KOD digital seismograph systems for nuclear test detection (see Section III-A), it is also being used with other digitally recording seismographs.

VII. CONCLUSIONS

A. SHORT-TO-INTERMEDIATE PERIOD SYSTEMS

1. Seismometers

Soviet design philosophy reflects a desire for magnification curves, either peaked or flat in the 0.1- to 1-Hz frequency range. This, in combination with the Soviets' overwhelming preference for galvanometric amplification and recording, leads to a need for seismometers with natural periods up to 4 or 5 sec. It is generally easier to scale down a Galitzin or Press-Ewing type seismometer for 5-sec operation than to increase the natural period of a typically lower-mass, translating-type-suspension, nominally 1-Hz seismometer such as the Willmore or Mark Products L4C geophone. Therefore, a need for natural periods of 4 to 5 sec resulted in the general use of pendulum-type seismometers of fairly large mass, equipped with zero-length springs for restoring moment and with cross-flexure hinges. The resulting short-period seismometers are quite large -- the KS, the newest experimental model, is 86 cm long and weighs 84 kg. The smallest seismometer appears to be the 2-sec SM-3 which is approximately 23 cm long and weighs 5.5 kg.

A practice followed in the design of virtually all short-period seismometers involves attaching the signal coil some distance beyond the center of oscillation of the pendulum (about 3 times the reduced length) to obtain mechanical amplification through leverage on the ground motion. This practice is used to compensate partially for transducer (coil-magnet) sensitivities which are generally poorer than sensitivities that result from coil-magnet systems of equivalent size made of modern, high-performance magnetic materials, such as some of the alnico alloys. It may also serve to produce higher level outputs to drive galvanometers or, where noise and sensitivity values warrant it, to drive amplifiers.

2. Galvanometers

Galvanometer sensitivities (about 10^{-9} amp/mm at 1 m for a 50-ohm coil and 1-Hz natural frequency) are similar to those of the U.S. models.

A difference exists in the large amount of open circuit damping present in the Soviet units (e.g., CDRX is about 10 times the coil resistance). This may reflect either air damping caused by the larger coil formers used or the presence of eddy-current damping (intentional or unintentional) in the magnetic circuit. Soviet galvanometers generally use a copper alloy suspension rather than the gold suspension normally used in U.S. designs.

3. Amplifiers

The standard UPN-3 short-period amplifier exhibits a maximum gain of 70 K and input RMS noise of 1 μV in the 0.5- to 10-Hz range. Both discrete and IC amplifiers available in the United States in the early 1970s were capable of voltage gains of 10^6 at equivalent input RMS noise levels of 0.05 μV. These differences are great and the low gain and high-input noise of the UPN-3 amplifiers doubtless contributes to difficulties in obtaining maximum noise-free magnification from relatively weak coil-magnet systems.

4. Recorders

The PS-3M drum recorder is similar to conventional photographic recorders universally employed in seismology in systems equipped with galvanometric recording. Visual ink-pen and hot-pen recorders are used, as are portable multichannel light-beam oscillographs. A high-resolution microphotorecorder for unattended operation, utilizing 70-mm film at a speed of 3.6 mm/min and at 0.2-mm line spacing (with a slowest speed of 1.75 m of film per month) appears to be quite sophisticated and reflects the current state of the art. An electrostatic time-delay transfer-type recorder is available for triggered application.

Magnetic-tape analog FM recording appears not to be standardized in respect to center frequencies and tape widths but is in use in several laboratories. Dynamic range claims of 35 to 40 dB are reasonable. However, the slow speed of 0.1 mm/sec (0.004 ips) direct-record system in the 0.03- to 1-Hz band is a major accomplishment.

5. Seismographs

In general, short-period seismograph systems operate at lower magnification at 1 Hz than equivalent U.S. seismographs (i.e., 10^4 vs 10^5). A peak magnification of 20,000 to 50,000 is termed high gain. More attention is given to obtaining flat magnification curves; this requires heavily-damped galvanometers with higher natural frequencies than the natural frequency of the seismometer. This approach is seldom followed in U.S. systems.

The short-period frequency range of interest seems to be 1 Hz and somewhat lower, as opposed to 1 Hz and a little higher in most U.S. systems. This may reflect generally lower microseisms in the Asian midcontinent than in the United States and greater attention to teleseismic and regional earthquakes.

A portable 3- or 4-component station utilizing magnetic tape recording has been developed for field network installation.

B. LONG-PERIOD SYSTEMS

1. Seismometers

The SKD and DS long-period seismometers are low-mass versions of the U.S. Press-Ewing-type models using zero-length springs in configurations not quite satisfying LaCoste suspension geometries. Coil-magnet transducers are less sensitive than equivalent U.S. systems, and it would appear that nonlinear behavior would limit their operation to natural periods of about 20 to 25 sec. Despite 1- to 2-kg inertial masses, the seismometers weigh 30 to 70 kg (presumably this includes cases). Sketchy descriptions of recent seismometer models indicate modifications in the spring, the inertial mass, and the hinges intended to improve stability at longer periods. Soviet seismologists have recently developed several types of feedback-controlled seismometers. In the most sophisticated model a signal from an unspecified displacement transducer fed back degeneratively to the damping-coil transducer through a low-pass filter with a long time-constant increases its stability at least 50 times in comparison with that of standard Soviet mechanical seismometers. Negative feedback signals proportional to velocity* and acceleration increase its damping and period, respectively.** This seismometer with a much improved sensitivity (as high as 30 mV/mm) and a natural period adjustable between 3 and 300 sec is comparable with the conventional long-period models developed in the United States. However, even this, the best Soviet long-period seismometer, does not have the stability, sensitivity, and environmental immunity of the most modern U.S. high-gain, long-period seismographs; these are capable of magnification $>10^5$ at 40 sec period.

2. Galvanometers

The Soviet and East German galvanometers appear to be of excellent quality, with natural periods of up to 500 sec in some experimental models. Galvanometer sensitivities are comparable to U.S. models. Copper alloy rather than gold is used as suspension material, and open circuit damping is extremely low.

3. Amplifiers

The 1 μV noise attained for solid-state amplifiers is sufficient for driving visual or magnetic-tape recorders or analog-to-digital converters.

4. Recorders

Photographic or visible-helical-drum recorders seem to be widely used. A relatively slow-speed FM tape unit with an almost unbelievable dynamic range of 57 dB (0.01 to 15 Hz) is described. A 10-bit analog-to-digital converter and multiple-channel digital recording system have also been developed.

---

*While not specifically mentioned by Soviet seismologists, velocity-feedback damping is superior to eddy-current damping; unlike eddy-current damping, velocity-feedback damping does not increase instrument noise due to increased Brownian motion.

**The use of degenerative feedback signals proportional to velocity and acceleration is probably necessary because the mechanical design of this seismometer does not allow clean operation at $T_s > 20$ sec.

5. Seismographs

Once again emphasis appears to be on flat magnification (usually ≤ 1000) over a wide frequency range. This is obtained with either a heavily-damped, short-period galvanometer (0.1- to 20-sec period response) or with a lightly damped, long-period galvanometer and heavily damped seismometer (1 to 100 sec). Experimentation with feedback, tiltmeters, Hall-effect transducers, and gyroscopic feedback are indicative of a search for better long-period systems. The shortcomings in stability at long periods due to geometry, hinges, and spring materials appears to have been solved only in the most recently developed experimental SD-III model.

C. DIGITAL SYSTEMS

The KOD and Triangle systems are 3- or 6-channel (3 long-period, 3 short-period) digital systems recording on magnetic tape at 33 11-bit words per second (similar to the FSK rate in the United States). Phototube galvanometer amplifiers (0.1 μV noise) are used with a notch filter, eliminating 6- to 8-sec microseisms.

A special-purpose computer is used to process the data. General-purpose computers for subsequent processing, described in Appendix A, appear to be more than adequate for seismological purposes (e.g., 0.6-μsec floating-point multiply, 64-bit word).

D. TELEMETRY

At Tashkent, Alma-Ata, and possibly Siberian locations, radio telemetry of local network data up to 50 km is employed, using fairly high RF power levels (tens of watts). Multiplexing of data channels is apparently possible, with analog and/or digital magnetic-tape recording. Borehole seismometers are utilized to depths of 1 km.

E. SPECIAL SYSTEMS

It would seem that the general unavailability of digital recording and processing has led to visual registration of data in required bandwidths. This is obvious in the multiple band-pass spectral analyzing systems, such as ChISS and PSS, which record 7 or 8 narrow-band output channels in the 20-Hz to 200-sec range.

Benioff-type quartz strainmeters of 10- to 40-m length, utilizing optical (direct and phototube amplifiers) or magnet-coil transducers, are used at several stations. The noise levels appear to be in the 10^{-9} range of strain.

F. TIMING SYSTEMS

Crystal clocks with stabilities of 10^{-9} and 10^{-8} per day are reported for laboratory and remote use, respectively. The power requirements of several watts for their clocks suggest that Soviet seismologists do not have micropower (CMOS) design components.

G. SUMMARY

From this study of Soviet seismometry certain general conclusions can be drawn about Soviet design philosophy, mechanical-electronic technology, and operational goals:

(1) Short-period seismometer design is constrained by a tendency toward massiveness, probably the result of low output coil-magnet systems and noise levels in amplifiers and galvanometers. Magnification of 20,000 to 50,000 at 1 Hz is considered high gain. Even the borehole 1-Hz seismometer is a zero-length spring pendulum design.

(2) Soviet seismologists show more interest in systems with flat response in the 1-to-10-sec period band than do U.S. seismologists. Except possibly for the most recently designed, experimental SVD-III and feedback-controlled models, Soviet long-period seismometers, with upper-period limits of near 25 sec and peak system magnifications of 1000, are apparently not as mechanically and geometrically precise as the modern U.S. Press-Ewing types.

(3) Wide use is made of mechanical gain (or attenuation). This is obtained by varying the coil position relative to the center of oscillation of the pendulum.

(4) In shaping response curves of Soviet instruments, much greater use is made of heavy damping than is made in the more conventional, critically damped models common in U.S. systems.

(5) Galvanometers are well developed for short-period applications and reflect the current state of the art at 100- to 500-sec periods.

(6) The noise of older Soviet solid-state amplifiers is one to two orders of magnitude higher than that of U.S. models.

(7) Frequency-modulated magnetic tape recording, while not standardized, seems to be well developed for slow-speed work, with reasonable signal-to-noise ratios.

(8) Digital systems are few, special purpose, and rather primitive.

(9) FM telemetry, both RF and audio frequency, is in use at a few networks, but not generally applied.

(10) Photo-optical technology is well developed as evidenced in the microphotorecorder.

(11) In recording, the emphasis seems to be on obtaining the records with the response needed in analysis -- as opposed to broadband, wide-dynamic-range recording and subsequent processing. This is also partially true in the few digital systems, where limited word lengths and sample rates necessitate some degree of signal conditioning. This is doubtless a consequence of the inaccessibility of computer-processing facilities for routine seismological studies.

Appendix A

SOVIET COMPUTERS USED IN SEISMOLOGY

Table A-1 gives the main parameters of the Soviet computers that are most frequently used in seismology. The specifications of the most recent line of third-generation Ryad computers, some of which have only lately been introduced, are given in Table A-2. The largest of the Ryad computers in Table A-2 are probably not available except for the highest priority applications.

Table A-1 [101]

MAIN PARAMETERS OF SOVIET COMPUTERS USED IN SEISMOLOGY

Parameters	BESM-4	BESM-6	Minsk-22	Minsk-32	M-222	Basoni
Word length (bits)	45	50	37	37	45	50
Addresses	3	1	2	2	3	1 & 3
Operating speed (μsec)						
average	50	1	200 to 167	33 to 25	37	25 to 10
add	47	1.1	--	15 to 40	--	6 to 13
multiply	94	1.9	--	15 to 125	--	up to 13
Main memory capacity (10^3 words)	8	32	8	16 to 65	32	32 to 65
Access time (μsec)	10	2	24	5	6	6
Secondary storage capacity						
drum (10^3 words)	64	132	--	--	0	--
tape (10^6 words)	4	32	1.6	12	8 to 40	48
Typewriter-input speed (cards/min)	700	700	200	600	700	700
Printer output speed (lines/min)	400	400	300	400	400	400

Preceding page blank

Table A-2 [101,102]

MAIN PARAMETERS OF SOVIET THIRD-GENERATION RYAD COMPUTERS

<table>
<tr><th>Parameters</th><th>R-20</th><th>R-30</th><th>R-40</th><th>R-50</th><th>R-60</th></tr>
<tr><td>Word length (bits)</td><td>16</td><td>32</td><td>64</td><td>64</td><td>64</td></tr>
<tr><td>Operating speed (μsec):</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>fixed-point add</td><td>20 to 30</td><td>5 to 11</td><td>0.9 to 2.1</td><td>1.0</td><td>0.4</td></tr>
<tr><td>fixed-point multiply</td><td>200 to 300</td><td>20 to 38</td><td>5.7 to 6.6</td><td>2.4</td><td>0.6</td></tr>
<tr><td>fixed-point divide</td><td>450 to 600</td><td>35 to 38</td><td>12 to 13</td><td>4.2</td><td>1.2</td></tr>
<tr><td>floating point add</td><td>50 to 70</td><td>7 to 10</td><td>2.5 to 3.5</td><td>1.5</td><td>0.4</td></tr>
<tr><td>floating point multiply</td><td>230 to 370</td><td>17 to 33</td><td>5.1 to 6.0</td><td>2.4</td><td>0.6</td></tr>
<tr><td>floating point divide</td><td>300 to 450</td><td>30 to 35</td><td>10 to 11</td><td>4.2</td><td>1.2</td></tr>
<tr><td>Average speed (10^3 opns/sec)</td><td>15 to 20</td><td>100</td><td>200 to 300</td><td>500</td><td>2000</td></tr>
<tr><td>Access time (μsec)</td><td>2</td><td>1 to 2</td><td>0.9</td><td>0.6 to 1</td><td>0.6</td></tr>
<tr><td>Main memory capacity (10^3 bytes)</td><td>64 to 256</td><td>128 to 512</td><td>128 to 1024</td><td>128 to 1024</td><td>4256 to 2048</td></tr>
<tr><td>Secondary storage capacity:</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>drum (10^6 bytes)</td><td>1.0</td><td>1.0</td><td>--</td><td>3.0</td><td>5.0</td></tr>
<tr><td>disc (10^6 bytes)</td><td>14.5</td><td>21.75</td><td>--</td><td>36.25</td><td>43.5</td></tr>
<tr><td>tape (10^6 bytes)</td><td>54</td><td>88</td><td>--</td><td>110</td><td>176</td></tr>
<tr><td>Input speed:</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>typewriter (char/sec)</td><td>10</td><td>10</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>cards (cards/min)</td><td>500</td><td>500</td><td>1000</td><td>1000</td><td>500,1200</td></tr>
<tr><td>papertape (char/sec)</td><td colspan="5">300, 1000, 1500</td></tr>
<tr><td>Output speed:</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>printer (lines/min)</td><td colspan="5">600, 900, 1200</td></tr>
<tr><td>cards (cards/min)</td><td>100</td><td>100</td><td>250</td><td>250</td><td>250</td></tr>
<tr><td>papertape (char/sec)</td><td colspan="5">100, 150, 200</td></tr>
</table>

Appendix B

NEW SOVIET SEISMOGRAPH STATIONS

Part I of this Report summarized the data on 54 base seismographic stations operating in the Soviet Union at the end of 1970 and 114 regional stations operating at the end of 1969. A recently published reference [103] made it possible to update the data on regional stations through the end of 1970 and to list five of at least two dozen additional stations which have become operational since January 1970. Four regional seismographic stations (Alla, Barguzin, Khaim, and Kyakhta) all located in Baykal were closed in 1970, but seven new regional stations began operating in the same year [103]. Table B-1 gives the pertinent data on seismographic stations which were not included in Part I of this Report. No data are available on the other stations which became operational in the Soviet Union since January 1971.

Table B-2, based on reference [109], summarizes the data (components and gain) on the standard SD-1 seismographs operating at Soviet seismographic stations by July 1972.

Table B-1

NEW SOVIET SEISMOGRAPH STATIONS

Station Name, Type[a], and Date It Began Operating	Seismograph	Maximum Gain (v_m)	Location	Seismic Zone	Reference
Arkit (r) (1970)	SKD SKM-3	1,000 25,000	41°48'N, 71°57'E (Kirgizia)	Central Asia	[103]
Arslanbob (r) (1970)	SKM-3	28,860	41°20'N, 71°51'E (Kirgizia)	Central Asia	[103]
Baldone (t) (1971-1972)	SK SD-1	-- 500	56°57'N, 24°06'E (Riga, Latvia)	--	[104]
Boom (r) (1970)	SVKM-3 SGKM-3	32,000 50,000	--	Baykal	[103]
Chita (r) (1970)	SKM-3	6,000	52°03'N, 113°30'E	Baykal	[103]
Kadzhi-Say[b] (r) (1970)	SK SKM-3	-- --	59°56'N, 82°34'E	Central Asia	[103]
Minsk (t) (1971-1972)	SKD SD-1	-- --	53°54'N, 27°34'E (Belorussia)	--	[105]
Noril'sk (b) (1973-1974)	--	--	69°21'N, 88°02'E	Arctic	[106]
Sheki (r) (1972)	SKM-3	--	41°12'N, 47°12'E (Azerbaydzhan)	Caucasus	[107]
Tkibuli (r) (1970)	SVKM-3 SGKM-3	21,000 22,000	42°22'N, 42°59'E (Georgia)	Caucasus	[103]
Ura-Tyube (r) (1970)	SVK SGK	1,000 1,400	39°55'N, 69°01'E (Kazakhstan)	Central Asia	[103]
Vilnius (t) (1971-1972)	SKD SD-1	-- --	54°41'N, 25°19'E (Lithuania)	--	[108]

[a]Regional stations are indicated by (r), base stations by (b), and teleseismic stations by (t).

[b]Formerly Rybach'ye.

Table B-2

SOVIET SEISMOGRAPHIC STATIONS THAT BY JULY 1972
HAD SD-1 SEISMOGRAPHS [109]

Station	Maximum Gain			Period in Operation
	N-S	E-W	Z	
Apatity	--	--	970	From August 1970
Bakuriani	-- --	-- --	560 1400	December 1971 to May 1972 From 1970
Garm	800 100	800 100	-- --	1968 to 1970 From 1970
Irkutsk	200	200	200	From March 1971
Iul'tin	1000 35[a]	980 35	980 --	From June 1970 From March 1972
Kishinev	-- 750	-- 750	1080 --	From January 1970 From October 1972
L'vov	-- 900?	-- 900?	900 --	From June 1969 From July 1972
Temporary Station No. 3	-- 770	-- 770	750 --	From January 1971 From January 1972
Moscow	--	--	1070	From January 1968
Petropavlovsk	1100 860	1100 960	1050 960	May 1969 to July 1972 From July 1972
Pulkovo	--	--	1000	From February 1970
Simferopol'	-- 830	-- 830	980 --	From November 1969 From November 1970
Sochi	--	--	1500	From August 1971

[a]Low-gain channel.

REFERENCES

1. Borisevich, Ye. S., and D. P. Kirnos (eds.), *Informatsionnyy spravochnik po seysmicheskoy apparature* (Handbook of Seismic Instruments), AN SSSR, Institut fiziki Zemli, No. 2, 1970.

2. Arkhangel'skiy, V. T., et al., *Apparatura i metodika nablyudeniy na seysmicheskikh stantsiyakh SSSR* (Instruments and Observation Methods at USSR Seismographic Stations), AN SSSR, Sovet po seysmologii, Moscow, 1962.

3. "The USF-4 Seismometer," Instrument specifications displayed at the Geodesy-Geophysics-71 exposition in Moscow during the 15th General Assembly, International Union of Geodesy and Geophysics, August 1971.

4. Kirnos, D. P., B. G. Rulev, and D. A. Kharin, "VEGIK Seismograph for Engineering Seismology Investigations and for Registration of Near Earthquakes," *Voprosy inzhenernoy seysmologii* (Problems of Engineering Seismology), No. 4, AN SSSR, Institut fiziki Zemli, Trudy, No. 16(183), 1961, pp. 32-56.

5. Tokmakov, V. A., "SM-2M Seismometer," *Seysmicheskiye pribory* (Seismic Instruments), AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 67-71.

6. Rulev, B. G., "The S5S Seismograph," *Apparatura i metodika seysmometricheskikh nablyudeniy* (Instruments and Seismic Observation Methods), AN SSSR, Institut fiziki Zemli, 1966, pp. 85-93.

7. "The S5S Seismometer," Instrument specifications displayed at the Geodesy-Geophysics-71 exposition in Moscow during the 15th General Assembly, International Union of Geodesy and Geophysics, August 1971.

8. Borisevich, Ye. S., and M. I. Yaroshevich, "Increasing the Quality Factor of Type GB-III Galvanometers," *Apparatura i metodika seysmometricheskikh nablyudeniy*, 1966, pp. 100-105.

9. Borisevich, Ye. S., and V. F. Katyushkin, "Type GB Galvanometers for Light-Beam Oscillographs Used in Seismology," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 19(186), 1961, pp. 69-72.

10. Borisevich, Ye. S., "The Balancing of Galvanometers Intended for the Registration of Strong Earthquakes," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 46-53.

Preceding page blank

11. Borisevich, Ye. S., "Light-beam Seismic Oscillographs," AN SSSR, *Izvestiya, Fizika Zemli*, No. 9, 1973, pp. 29-42.

12. Zayonchkovskiy, M. A., and I. M. Rozenberg, "Transistorized Low-Frequency Amplifier," *Apparatura i metodika seysmometricheskikh nablyudeniy*, AN SSSR, Institut fiziki Zemli, 1966, pp. 79-84.

13. Rykov, A. V., "Theory and Approximate Calculation of Parametric Inductance" (Variable Reluctance Amplifier), AN SSSR, *Izvestiya, Fizika Zemli*, No. 1, 1969, pp. 79-85.

14. Borisevich, Ye. S., S. A. Kastorskiy, and M. S. Mosyagina, "Modernized OSB-VI-M Seismic Oscillograph," *Novyye pribory dlya registratsii seysmicheskikh yavleniy* (New Instrument for the Registration of Seismic Effects), AN SSSR, Institut fiziki Zemli, Trudy, No. 35(202), 1964, pp. 43-48.

15. Aronov, L. Ye., "A Photoelectric Device for Controlling the Registration of Electrical Processes," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, Trudy, No. 19(186), 1961, pp. 37-39.

16. Borisevich, Ye. S., S. A. Kastorskiy, and M. S. Mosyagina, "OSB-IMp Portable Seismic Oscillograph," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 90-98.

17. Aksenovich, G. I., et al., "Direct Ink-Pen Recorders," *Eksperimental'naya seysmologiya* (Experimental Seismology), AN SSSR, Institut fiziki Zemli, 1971, pp. 43-51.

18. Borisevich, Ye. S., V. B. Preobrazhenskiy, and V. V. Stepanov, "The N-002 Three-Channel Seismic [Hot-] Pen Recorder," *Novyye pribory dlya registratsii seysmicheskikh yavleniy*, AN SSSR, Institut fiziki Zemli, Trudy, No. 35(202), 1964, pp. 30-35.

19. Pol'skiy, E. M., "Pen-Recording Units," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 133-138.

20. Borisevich, Ye. S., V. B. Preobrazhenskiy, and V. V. Stepanov, "PP-6 Six-Channel [Hot-] Pen Recorder," *Novyye pribory dlya registratsii seysmicheskikh yavleniy*, AN SSSR, Institut fiziki Zemli, Trudy, No. 35(202), 1964, pp. 54-60.

21. Begushin, G. K., and Ye. S. Borisevich, "Some Results of Tests on a Model of the PEO-I Electrostatic Light-Beam, Oscillograph with Visual Recording on Plain Strip-Chart Paper," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 7, 1973, pp. 18-23.

22. Begushin, G K., "Investigation of the PEO-I Electrostatic Light-Beam Oscillograph," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 7, 1973, pp. 23-29.

23. Zhilyayev, I. I., and L. N. Rykunov, "Some Characteristics of Low-Speed Magnetic Recording of Processes in the Period Range of 1 to 30 Seconds," AN SSSR, *Izvestiya, Fizika Zemli*, No. 2, 1969, pp. 71-74.

24. Chichinin, I. S., G. B. Yegorov, A. V. Yemel'yanov, and A. I. Bochanov, "Transportable Telemetering Taiga Seismic Station," *Metodika seysmicheskikh issledovaniy* (Methods of Seismic Investigations), AN SSSR, *Sibirskoye otdeleniye instituta geologii i geofiziki* (Transactions of the Siberian Branch of the Institute of Geology and Geophysics, Academy of Sciences USSR), Trudy, No. 46, 1969, pp. 95-119.

25. Mishatkin, V. N., "Application of Analog Magnetic Recording of Seismic Signals," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 7, 1973, pp. 68-74.

26. Shnirman, G. L., "Recent Trends in the Development of Soviet Instruments for Seismic Investigations," AN SSSR, *Izvestiya, Fizika Zemli*, No. 10, 1974, pp. 121-126.

27. Aranovich, Z. I., O. A. Korchagina, and G. A. Kudryavtseva, "Standardization of the Frequency-Response Curves of High-Gain Seismographs," *Apparatura i metodika seysmometricheskikh nablyudeniy*, AN SSSR, Institut fiziki Zemli, 1966, pp. 106-114.

28. *Parametry, amplitudno-chastotnyye i fazovyye kharakteristiki priborov opornykh seysmicheskikh stantsiy SSSR, 1969* (Instrumental Constants and Magnification and Phase Shift Curves of USSR Base Seismographic Stations, 1969), addendum to *Seysmologicheskiy byulleten' seti opornykh seysmicheskikh stantsiy SSSR* (Seismological Bulletin of the USSR Network of Base Seismographic Stations), AN SSSR, Institut fiziki Zemli, Moscow, 1972.

29. Alvarez, U., P. Blanco, S. V. Medvedev, et al., "Seismic Condition in Santiago de Cuba," AN SSSR, *Izvestiya, Fizika Zemli*, No. 5, 1973, pp. 81-86.

30. Aksenovich, G. I., Ye. I. Gal'perin, R. M. Gal'perina, V. G. Katrenko, and P. A. Troitskiy, "Investigation of a Decrease in the Background of Seismic Noise with Depth in Alma-Ata and Tashkent," AN SSSR, *Izvestiya, Fizika Zemli*, No. 11, 1972, pp. 67-76.

31. Urazayev, B. M., A. B. Ospanov, and T. Kh. Duysebayev, "Alma-Ata Central Seismographic Station," AN Kazakhskoy SSR, *Vestnik*, No. 5, 1973, pp. 3-12.

32. Novitskiy, M. A., and Yu. V. Sirotskiy, "Electrochemical Seismometer," *Priroda*, No. 1, 1970, p. 118.

33. Aksenovich, G. I., Ye. I. Gal'perin, B. M. Grafov, P. D. Lukovtsev, M. A. Novitskiy, Yu. V. Sirotskiy, and L. A. Sokolov, "Preliminary Results of Testing an Electrochemical Seismometer," AN SSSR, *Izvestiya, Fizika Zemli*, No. 2, 1970, pp. 81-87.

34. "The ASS Seismic System," Instrument specifications displayed at the Geodesy-Geophysics-71 exposition in Moscow during the 15th General Assembly, International Union of Geodesy and Geophysics, August, 1971.

35. Shnirman, G. L., "Three-Component Galvanometric Microphoto-recording Device for Analog Recording of Electrical Currents," *Author's Certificate 368567*, Applied for 24 November 1969, Granted 26 February 1973.

36. Pomerantseva, I. V., A. N. Mozzhenko, I. A. Sokolova, and G. V. Yegorkina, "Results of Regional Investigations of the Crystalline Layer of the Earth's Crust and Upper Mantle by Zemlya Systems," *Metodika, tekhnika, i resul'taty geofizicheskoy razvedki: materialy V Vsesoyuznoi Nauchno-Tekhnicheskoy Geofizicheskoy konferentsii v gorode Novosibirske* (Methods, Techniques, and Results of Geophysical Exploration: Proceedings of the Fifth All-Union Scientific-Technical Geophysical Conference in Novosibirsk), Moscow, 1967, pp. 20-25.

37. Pomerantseva, I. V., and A. N. Mozzhenko, "Methods and Some Results of Crustal Investigations by Zemlya Systems," *Glubinnoye seysmicheskoye zondirovaniye: materialy Vtorogo Vsesoyuznogo soveshchaniya po izucheniyu kory i verkhney mantii Zemli metodami seysmologii vzryvov* (Deep Seismic Sounding: Proceedings of the Second All-Union Conference on Crustal and Upper Mantle Investigations by Explosion Seismology), Alma-Ata, 1973, pp. 137-150.

38. Pomerantseva, I. V., A. N. Mozzhenko, G. V. Yegorkina, and I. A. Sokolova, "Methods and the Principal Results of Investigating the Deep Structure of the Crust and the Upper Mantle by Zemlya Systems," *Metodika i resul'taty kompleksnykh glubinnykh geofizicheskikh issledovaniy* (Methods and Results of Deep Geophysical Investigations), Leningrad, 1969, pp. 196-207.

39. Pak, V. A., A. R. Mitrofanov, R. Z. Akhmerov, V. P. Surov, and A. M. Nasyrov, "Regional Crustal Investigations by Zemlya Systems," *Glubinnoye stroyeniye zemnoy kory Uzbekistana po geologo-geofizicheskim issledovaniyam* (Deep Crustal Structure of Uzbekistan from Geological-Geophysical Investigations), Tashkent, 1971, pp. 42-43.

40. Rykunov, L. N., and V. V. Sedov, "Ocean-Bottom Seismograph," AN SSSR, *Izvestiya, Fizika Zemli*, No. 8, 1967, pp. 83-87.

41. Rykunov, L. N., and V. V. Sedov, "Seismic Noise in the Frequency Range 2 to 15 Hz on the Bottom of the Black Sea," AN SSSR, *Izvestiya, Fizika Zemli*, No. 7, 1965, pp. 30-39.

42. Neprochnov, Yu. P., L. N. Rykunov, and V. V. Sedov, "Experience with Ocean-Bottom Seismographs During Deep Seismic Sounding," AN SSSR, *Izvestiya, Fizika Zemli*, No. 11, 1968, pp. 71-77.

43. Rykunov, L. N., "Direct Seismological Observations on the Sea and Ocean Floors," *Geofizicheskiy byulleten'*, No. 21, 1970, pp. 40-50.

44. Kirnos, D. P., O. Ye. Starovoyt, "Experience with the SD-1 Long-Period Seismograph," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 151-156.

45. Borisevich, Ye. S., "Development of a Series of Instruments for Scientific Geophysical Research," AN SSSR, *Izvestiya, Fizika Zemli*, No. 11, 1970, pp. 101-109.

46. Feofilaktov, V. D., M. I. Yaroshevich, and N. D. Mansurova, "Experience with the SPG-4 Long-Period Galvanometer," AN SSSR, *Izvestiya, Fizika Zemli*, No. 12, 1972, pp. 77-80.

47. "The DG-100 and DG-300 Long-Period Mirror Galvanometers," Instrument specifications displayed at the Geodesy-Geophysics-71 exposition in Moscow during the 15th General Assembly, International Union of Geodesy and Geophysics, August, 1971.

48. Teupser, Ch., G. Genschel, and W. Ribnitz, "Langperiodische Seismographen mit 330-s-Galvanometer," *Gerlands Beiträge zur Geophysik*, Vol. 80, No. 6, 1971, pp. 469-474.

49. Yaroshevich, M. I., and N. D. Mansurova, "A 180-sec Galvanometer," AN SSSR, *Izvestiya, Fizika Zemli*, No. 12, 1968, pp. 77-80.

50. Teupser, Ch., "Seismological Instruments Developed at the Institute of Geodynamics, Jena," *Trudy desyatoy general'noy assamblei evropeyskoy seysmologicheskoy komissii* (Proceedings of the Tenth Assembly of the European Seismological Commission, Leningrad, September 3-11, 1968), Moscow, AN SSSR, Sovetskiy geofizicheskiy komitet, Vol. 2, 1970, pp. 448-461.

51. Feofilaktov, V. D., and M. I. Yaroshevich, "Long-Period Seismic Velocity Meter with Galvanometric Recording," AN SSSR, *Izvestiya, Fizika Zemli*, No. 7, 1971, pp. 84-87.

52. Yaroshevich, M. I., "Ultralong-Period Galvanometers," AN SSSR, *Izvestiya, Fizika Zemli*, No. 8, 1970, pp. 88-89.

53. Yaroshevich, M. I., "Degree of Air Damping of the Coil Assembly of Long-Period Galvanometers," AN SSSR, *Izvestiya, Fizika Zemli*, No. 8, 1969, pp. 87-90.

54. Yaroshevich, M. I., and N. D. Mansurova, "Long-Period Galvanometer," AN SSSR, *Izvestiya, Fizika Zemli*, No. 12, 1967, pp. 60-63.

55. Kirnos, D. P., V. T. Arkhangel'skiy, Z. I. Aranovich, and V. D. Feofilaktov, "General-Type Broadband Seismographs and a Unified Method of Determining Constants," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 3-34.

56. Arkhangel'skiy, V. T., D. P. Kirnos, A. V. Rykov, and V. N. Solov'yev, "Broadband Long-Period Visual-Recording Seismograph," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 7, 1973, pp. 51-56.

57. Kirnos, D. P., V. D. Feofilaktov, and M. I. Yaroshevich, "SD-2 Seismic Channel," AN SSSR, *Izvestiya, Fizika Zemli*, No. 3, 1972, pp. 57-58.

58. "Magnification Curves of Seismographs at the Obninsk Station in 1971," unpublished.

59. Kirnos, D. P., and M. I. Yaroshevich, "Wideband Seismograph with Constant Gain in the Period Range between Two and Two Hundred Seconds," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 3-5.

60. Gostev, M. A., and L. L. Shul'pin, "Long-Period Seismograph," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 5-8.

61. Aksenovich, G. I., Kh. Kh. Gazizov, Yu. G. Kristev, and I. L. Nersesov, "Seismic Channel for Registration of Long Periods," *Eksperimental'naya seysmologiya* (Experimental Seismology), 1971, pp. 17-20.

62. Aksenovich, G. I., and Yu. G. Kristev, "An FM Magnetic Tape Recording Unit," *Eksperimental'naya seysmologiya*, 1971, pp. 12-17.

63. Zheleznyak, T. K., "Long-Period Gyroseismometer," AN SSSR, *Izvestiya, Fizika Zemli*, No. 4, 1974, pp. 78-82.

64. Pasechnik, I. P., *Kharakteristika seysmicheskikh voln pri yadernikh vzryvakh i zemletryaseniyakh* (Characteristics of Seismic Waves from Nuclear Explosions and Earthquakes), Moscow, 1970.

65. Osadchiy, A. P., and S. K. Daragan, "The KOD Digital Seismograph System," *Vychislitel'naya seysmologiya, Mashinnaya interpretatsiya seysmicheskikh voln* (Computational Seismology, Computer Interpretation of Seismic Waves), AN SSSR, Institut fiziki Zemli, No. 2, 1966, pp. 183-195.

66. Goncharov, V. L., "High-Speed Digital Computer for Processing Geophysical Data," *Apparatura i metodika seysmometricheskikh nablyudeniy*, AN SSSR, Institut fiziki Zemli, 1966, pp. 152-159.

67. Goncharov, V. L., "A System for Preliminary Processing of Seismic Data," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 94-97.

68. Osadchiy, A. P., "Magnification of a Digital Seismograph System," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 108-110.

69. Daragan, S. K., and A. P. Osadchiy, "Pulse Calibration and Control of a Seismic Channel," *Vychislitel'naya seismologiya, Metody i programmy dlya analiza seysmicheskikh voln* (Computational Seismology, Methods and Algorithms for the Analysis of Seismic Waves), AN SSSR, Institut fiziki Zemli, No. 3, 1967, pp. 245-253.

70. Bashilov, I. P., P. V. Kevlishvili, V. N. Knyazev, Yu. A. Kolesnikov, B. M. Naymark, and A. P. Osadchiy, "A System for the Digital Magnetic Recording and Processing of Seismic Signals Acquired by the Triangle Array," AN SSSR, *Izvestiya, Fizika Zemli*, No. 2, 1974, pp. 85-93.

71. Kolesnikov, Yu. A., and L. N. Malinovskaya, "Impulsive Seismic Wave," AN SSSR, *Doklady*, Vol. 204, No. 1, 1972, pp. 80-83.

72. Kolesnikov, Yu. A., A. L. Levshin, and V. F. Pisarenko, "Verification of the Hypothesis Concerning the Existence of Microseisms of Cosmic Origin (Seismic Signals at Pulsar Frequencies)," *Vychislitel'naya seismologiya, Mashinnyy analyz tsifrovykh seysmicheskikh dannykh* (Computational Seismology, Computer Analysis of Digital Seismic Data), AN SSSR, Institut fiziki Zemli, No. 7, 1974, pp. 266-278.

73. Katrenko, V. G., and V. I. Ulomov, "Automation of Seismological Observations in Uzbekistan," *Seysmichnost' Zapadnogo Uzbekistana* (Seismicity of Western Uzbekistan), AN Uzbekskoy SSR, Institut seysmologii, Tashkent, 1972, pp. 138-144.

74. Yakubov, M. S., "Some Methods and Apparatus for Telemetering Seismic Data," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 7, 1973, pp. 74-79.

75. Kvashin, Ye. V., and S. A. Chermashentsev, "A System for Operational Input of Seismic Data into a Computer," AN Uzbekskoy SSR, *Izvestiya, Seriya technicheskikh nauk*, No. 6, 1973, pp. 7-9.

76. Nersesov, I. L., Ye. I. Gal'perin, L. M. Vorovskiy, and R. M. Gal'perina, "Alma Ata High-Sensitivity Telemetering Seismographic Station Network," AN SSSR, *Izvestiya, Fizika Zemli*, No. 7, 1974, pp. 72-77.

77. Katrenko, V. G., "A Method of Transmitting Seismic Data," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 6, 1972, pp. 160-166.

78. Bugaevskiy, G. N., A. P. Leont'yev, V. I. Naydich, N. G. Shvetsov, V. I. Borisov, and Yu. B. Kashtanov, "Centralized Seismic System," Author's Certificate 313191, Applied 2 July 1970, Granted 31 August 1971.

79. Tigranyan, G. A., "Multichannel Telemetering System for Investigating Problems Related to Earthquake Prediction," AN Armyanskoy SSR, *Izvestiya, Seriya tekhnicheskikh nauk*, Vol. 25, No. 6, 1972, pp. 19-23.

80. Khalturin, V. I., "Seismic Wave Absorption in the Crust of Tien Shan," *Eksperimental'naya seysmologiya*, 1971, pp. 125-136.

81. Zapol'skiy, K. K., "Multiple Bandpass ChISS Seismographs," *Eksperimental'naya seysmologiya*, 1971, pp. 20-36.

82. Pavlova, I. N., "Dynamic Characteristics of the Aleutian Earthquake of February 4, 1965, and Its Aftershocks from the Records of ChISS Seismographs," *Eksperimental'naya seysmologiya*, 1971, pp. 163-179.

83. Zapol'skiy, K. K., and R. P. Solov'yeva, "Spectral Characteristics of the Strong Alaska Earthquake of March 28, 1964, and Its Aftershocks," *Eksperimental'naya seysmologiya*, 1971, pp. 152-163.

84. Kondorskaya, N. V., and Z. I. Aranovich, "Methodological Basis for Optimizing a Seismic Observation System," AN SSSR, *Izvestiya, Fizika Zemli*, No. 7, 1971, pp. 14-30.

85. Zhigal'tsev, A. A., and M. P. Zarayskiy, "Instruments for Registering Long-Period Seismic Oscillations," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, No. 5, 1969, pp. 72-89.

86. Latynina, L. A., Ye. Ya. Starkova, V. A. Podgornykh, and R. M. Karmaleyeva, "Crustal Strains at the Kondar Station of Tadzhik SSR," AN SSSR, *Izvestiya, Fizika Zemli*, No. 3, 1968, pp. 75-84.

87. Nersesov, I. L., L. A. Latynina, N. A. Zharinov, R. M. Karmaleyeva, and A. M. Sadovskiy, "Results of Crustal Strain Measurements at the Garm Test Site," *Poiski predvestnikov zemletryaseniy na prognosticheskikh poligonakh* (Search for Earthquake Forerunners at Earthquake Prediction Test Sites), 1974, pp. 60-65.

88. Savarenskiy, Ye. F., I. L. Nersesov, R. M. Karmaleyeva, and L. A. Latynina, "Long-Period Waves from the Aleutian Earthquake of February 4, 1965, Recorded by Quartz Strainmeters," AN SSSR, *Izvestiya, Fizika Zemli*, No. 5, 1966, pp. 33-42.

89. Bulatsen, V. G., "Preliminary Results of Observations of Tidal Strains in Crimea," *Vrashcheniye i prilivnyye deformatsii Zemli* (Rotation and Tidal Strains of the Earth), No. 4, 1972, pp. 3-20.

90. Starovoyt, O. Ye., V. D. Feofilaktov, L. L. Shul'pin, and M. I. Yaroshevich, "Quartz Strainmeter at the Obninsk Central Seismographic Station," AN SSSR, *Izvestiya, Fizika Zemli*, No. 11, 1971, pp. 85-94.

91. Karmaleyeva, R. M., "Investigation of Long-Period Surface Waves by Quartz Strainmeters," AN SSSR, *Izvestiya, Fizika Zemli*, No. 9, 1972, pp. 25-38.

92. Karmaleyeva, R. M., L. A. Latynina, and Ye. F. Savarenskiy, "On the Observation of Long-Period Waves with Quartz Extensometers," *Pure and Applied Geophysics*, Vol. 82, 1970/V, pp. 85-97.

93. Latynina, L. A., and R. M. Karmaleyeva, "Preliminary Results of Observations by Horizontal Strainmeter in Tien Shan," AN SSSR, *Izvestiya, Seriya geofizicheskaya*, No. 11, 1962, pp. 1574-1578.

94. Balavadze, B. K., R. M. Karmaleyeva, K. Z. Kartvelishvili, and L. A. Latynina, "Observation of Terrestrial Tidal Strains by Horizontal Strainmeter in Tbilisi," AN SSSR, *Izvestiya, Fizika Zemli*, No. 2, 1965, pp. 75-79.

95. Balavadze, B. K., and K. Z. Kartvelishvili, *Nablyudeniya zemnykh prilivov v Tbilisi* (Observation of Earth Tides in Tbilisi), 1972, 138pp.

96. Giss, R. Ye., N. A. Zharinov, and V. Ya. Stepanov, "Displacements and Strains at the Toktogul Hydroelectric Power Installation," *Sovremennyye dvizheniya zemnoi kory* (Recent Crustal Movements), No. 5, 1973, pp. 216-222.

97. Preobrazhenskiy, V. B., "A Magnetic-Memory, Visual-Recording Device for Registration of Distant Earthquakes," *Novyye pribory dlya registratsii seysmicheskikh yavleniy*, AN SSSR, Institut fiziki Zemli, Trudy, No. 35(202), 1964, pp. 49-53.

98. Preobrazhenskiy, V. B., "A Recording Device with Magnetic Memory for Registration of Distant Earthquakes," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, Trudy, No. 26(193), 1963, pp. 78-84.

99. Vetchinkin, A. N., and V. B. Preobrazhenskiy, "An Automatic Seismic Recording Unit with Magnetic Memory," *Seysmicheskiye pribory*, AN SSSR, Institut fiziki Zemli, Trudy, No. 19(186), 1961, pp. 52-56.

100. Kolesnikov, Yu. A., and V. N. Solov'yev, "A Device for Digitizing Seismograms with the Numbers Automatically Punched on Cards and Paper Tape," *Novyye pribory dlya registratsii seysmicheskikh yavleniy*, AN SSSR, Institut fiziki Zemli, Trudy, No. 35(202), 1964, pp. 12-21.

101. Polshkov, M. K., *Teoriya analogovoy i tsifrovoy seismorazvedochnoy apparatury* (Theory of Analog and Digital Equipment for Seismic Exploration), Moscow, 1973.

102. Holland, W. B., *Unified System Compendium*, The Rand Corporation, R-1500/3, special issue of *Soviet Cybernetics Review*, Vol. 4, No. 3, 1974, pp. 1-58.

103. Vvedenskaya, N. A., N. V. Kondorskaya, and N. V. Shebalin, editors, *Zemletryaseniya v SSSR v 1970 godu* (Earthquakes in the USSR in 1970), AN SSSR, Institut fiziki Zemli, Moscow, 1973.

104. Proskuryakova, T. A., and V. G. Alkaz, "Investigation of Long-Period Microseisms in the Range of 10 to 150 Seconds," AN SSSR, *Izvestiya, Fizika Zemli*, No. 6, 1973, pp. 88-92.

105. Khot'ko, Zh. P., "Seismological Investigations," *Voprosy fiziki okolozemnogo prostranstva i zemnykh nedr Belorussii* (Problems of the Physics of Near Space and the Earth's Interior), 1972, pp. 55-68.

106. *Operativnyy seysmologicheskiy byulleten', yezhedekadnyy* (Ten-Day Seismological Bulletin), AN SSSR, Institut fiziki Zemli, Obninsk Central Seismological Observatory, Nos. 1-28, 1974.

107. Azerbaydzhan Information Agency, "Another Earthquake Monitor," *Vyshka* (Tower), January 23, 1973, p. 4, cols. 1-2.

108. Khot'ko, Zh. P., "Results and Problems of Geophysical Investigation of the Deep Structure of the Territory of Belorussia and Baltic Countries," *Voprosy geologii Belorussii* (Geological Problems of Belorussia), 1973, pp. 66-70.

109. Feofilaktov, V. D., and V. A. Masloboyev, "A Comparison of the Dynamic Characteristics of Standard High-Gain Soviet and U.S. Seismographs," AN SSSR, *Izvestiya, Fizika Zemli*, No. 1, 1975, pp. 95-100.